ARCOM

ASSOCIATION OF RESEARCHERS IN **CONSTRUCTION MANAGEMENT**

LARGE INFRASTRUCTURE PROJECTS: CHALLENGES AND OPPORTUNITIES

DOCTORAL WORKSHOP

4TH JULY 2019, 5TH JULY 2019
9:30 – 4:30PM

WORKSHOP PROCEEDINGS

DEAKIN UNIVERSITY
MELBOURNE
AUSTRALIA

DEAKIN
UNIVERSITY

INTRODUCTION

Infrastructure projects (e.g. rail, roads, bridges, dams, oil & gas platforms, underground metros, etc.) facilitate economic and social activity in an economy. These assets form the critical lifeblood of economic prosperity and development of nations. The Australian Government has thus placed sustained emphasis on economic growth and productivity by investing significantly in major capital infrastructure - $75 billion was committed to funding road and rail infrastructure projects nationwide between 2017-2027 in the 2017 Budget [2, 3].

However, these projects are notorious for the many performance challenges that beset their planning, procurement and delivery – for example, more than 50% of large infrastructure projects experience significant cost and schedule overruns [4-7]. The 12km Sydney Light Rail project currently on-going is already making headlines for being a year behind schedule and could become the costliest rail project with a possible price tag of $3billion instead of the original estimate of $1.5billion [8, 9].

This workshop will be structured to allow the presentation and discussion of current infrastructure delivery problems and solutions. This will create the opportunity to ask critical questions, test ideas and initial hypothesis or solutions, as well as provide a debating forum that will help sharpen our collective understanding of the complexities associated with planning, appraisal, design, finance and governance of large infrastructure projects.

Presentations would cover the following themes (not exhaustive):

- Project Risk Quantification and Analysis
- Integrated Strategic Asset Management
- Infrastructure planning & Investment analysis
- Benefits assessment in megaprojects
- PPPs and infrastructure delivery
- Sustainable and resilient infrastructure
- Megaproject failure and success
- Value Capture and Major Land Transport Infrastructure
- Front-End Project Governance
- Megaproject complexity, risk and uncertainty management
- Future-Proofing Infrastructure
- Current and emerging infrastructure issues in Australasia

PEER REVIEW NOTE:

Each paper was double-blind peer-reviewed by 2 established academics on the subject matter. Accepted papers will be published as part of the ARCOM Doctoral Workshop proceedings. For more information on past ARCOM Doctoral Workshops – see http://www.arcom.ac.uk/workshops.php

WORKSHOP CONVENOR:

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References

1. Deloitte Access Economics, *Value of Rail - The contribution of rail in Australia*. 2017, Deloitte Access Economics for Australasian Railway Association (ARA).
2. Department of Infrastructure and Regional Development. *Infrastructure Investment*. 2017 16-07-2017]; Available from: http://investment.infrastructure.gov.au/.
3. The Commonwealth of Australia. *Budget 2017*. Stronger growth to create more and better paying jobs: Building Australia 2017 16-07-2017]; Available from: http://budget.gov.au/2017-18/content/glossies/jobs-growth/html/jobs-growth-01.htm.

4. Productivity Commission, *Public Infrastructure: Productivity Commission Report*. 2014, Australian Government: Melbourne, Victoria, Australia.
5. Love, P.E., D.D. Ahiaga-Dagbui, and Z. Irani, *Cost overruns in transportation infrastructure projects: Sowing the seeds for a probabilistic theory of causation.* Transportation Research Part A: Policy and Practice, 2016. **92**: p. 184-194.
6. Caraval Group, *A Review of Project Governance Effectiveness in Australia*. 2013, A Report for the Australian Government, Infrastructure Australia.
7. Ahiaga-Dagbui, D.D., et al., *Toward a systemic view to cost overrun causation in infrastructure projects: a review and implications for research.* Project management journal, 2017. **48**(2): p. 88-98.
8. Cockburn, P., *Sydney light rail contractor Acciona suing NSW Government; further delays to construction likely*, in *ABC News*. 2018.
9. O'Sullivan, M., *Sydney light rail's finish date now 2020, a year later than planned*, in *Sydney Morning Herald*. 2018, Sydney Morning Herald: Online.

EDITORIAL NOTE

This doctoral workshop, the first ARCOM workshop in Australia, was organised to allow the presentation of ongoing PhD studies in the area of large infrastructure delivery. This created the opportunity to ask critical questions, test ideas and initial hypothesis, as well as provide a debating forum that will help sharpen our collective understanding of the complexities associated with planning, appraisal, design, finance and governance of large infrastructure projects.

The workshop had 20 attendees (with an additional 5 joining in via an online live webcast). Ten abstracts were received and reviewed by two established researchers. Six papers were accepted after the double-blind reviews. These include:

Mustafa A. Hilal (Swinburne University) presented a paper on the barriers to BIM adoption for facilities management in Australia. The three most important factors identified include unknown facilities data requirements, a lack of facilities management team participating in the design phase, and the training requirements needed by facilities managers to become familiar with using the BIM technology at before project training before hand-over stage. *Co-authors: Tayyab Maqsood, Amir Abdekhodaee.*

Arka Ghosh (Deakin University) presented a paper on the application of the internet of things in the Australian construction industry. The study asserts that Internet-of-Things (IoT) is set to add $75-96 billion annually through tangible and intangible cost savings. The paper thus explores the opportunities that IoT provides to the Australian construction sector while providing a conceptual framework for its smooth uptake to maximize the benefit generated. *Co-author: M. Reza Hosseini*

Hongyu Jin (Deakin University) presented ongoing PhD studying on determining the optimal concession period to cope with the uncertainties in public-private partnerships. Public-private partnership (PPP) has been widely used in delivering infrastructure projects, such as freeway, tunnel and bridge. The study develops a concession period determination model based on expanded net present value and bargaining game theory. The model attempts to incorporate the influence of risk preferences held by project parties on the length of the concession period. Additionally, the financial risks borne by both parties are measured to verify the risk control ability of the concession period. *Co-author: Chunlu Liu*

Benito Mignacca, (Leeds University, UK) presented the results of a systematic review of the extant research that examines the state of the art and way-forward in linking circular economy and modularisation in energy-related projects. The paper argues that despite the growing interest among policymakers, academics and industry in both circular economy and modularisation, there is a lack of research about the link between circular economy, energy infrastructure and modularisation. The study then posses a number of questions for future research including: What are the implications of the link between circular economy and modular energy infrastructure from a legal point of view? Which is the impact of the link between modularisation and circular economy on the end of life cost? How are module lifting and transportation exactly related to the link between modularisation and circular economy? These questions form the basis of further studies in this ongoing PhD study. *Co-author: Giorgio Locatelli*

Hamidreza Karami (Curtin University) presented a study that examines the intersection of knowledge management and value engineering at the front-end of marine infrastructure projects to support successful project delivery. The paper highlights the challenges of knowledge capture, sharing and learning to support value engineering on marine projects. *Co-authors: Loza Ahmadi, Oluwole Alfred Olatunji*

Thomas Moore (Arcadis, Australia) – presented the only *industry-stream* (non-PhD research) paper on risk management of rail infrastructure megaprojects in Australia. The Australian government is providing significant investment in infrastructure, with a projected $75 billion to be spent over the next 10 years. It is well documented that megaprojects typically struggle to meet their baseline targets in terms of schedule and cost. The author argues that despite the importance of effective risk management for the successful delivery of megaprojects, it remains one of the least developed areas in the industry. This presentation thus detailed some of the key attributes of effective risk management to facilitate successful project delivery. The author argues that "rail infrastructure megaprojects should be treated more like an organisation than a conventional project", with risk management framework that can cope with the high complexity and uncertainty involved in integrating several stakeholders and key project actors.

There were three keynote presentations from **Dr Igor Martek** (Deakin University), **Dr Ajibade Aibinu** (University of Melbourne) and **Dr M. Reza Hosseini** (Deakin University). Dr Martek's presented on the topic 'infrastructure as an instrument of national strategy', comparing the scale, long-term planning and investment in major infrastructure in Australia and China.

Dr Hosseini provided tips for where to publish, when to publish, who to co-author with, dealing with reviewer feedback and surviving the 'publish or perish' environment prevalent in academia. Dr Aibinu keynote focussed on how to get the most out of the PhD process and navigating the challenges of undertaking a PhD. Dr Aibinu has previously been an Assistant Dean of Research Training and a Member of the University of Melbourne's Research Training Advisory Committee. This gave him a unique insight into the challenges faced by PhD students.

The workshop concluded with an engaging Q&A session with Drs Hosseini, Martek and Aibinu as panel members.

Overall, the workshop was a great success and I want to thank everyone who attended or contributed to it in some way. I thank ARCOM for funding the travel and accommodation for some of the students who were travel interstate.

Dr Dominic Ahiaga-Dagbui
Deakin University
August 2019

CONTENTS

DEAKIN UNIVERSITY

Large Infrastructure Project Delivery: Challenges and Opportunities

Location: Deakin Downtown, 727 Collins St | Tower #2, Level 12 Melbourne, VIC 3008 | Australia
Date: 4th of July 2019
Time: 9:30 – 3pm

Time	Item	Speaker/Authors	Organisation	
9:30	**Registration Opens**			
10:00	Welcome	Dr Ahiaga-Dagbui	Deakin University	
	Video Welcome	Prof Chris Gorse	Chair, ARCOM (UK)	
10:15	Paper 1	Thomas Moore	Arcadis (Australia)	Risk Management of Rail Infrastructure Megaprojects
10:35	Paper 2	**Mustafa A. Hilal**, Tayyab Maqsood, Amir Abdekhodaee	Swinburne University (Australia)	Impeding factors for BIM adoption in Facilities Management
10:50	Paper 3	**Hamidreza Karmi**, Loza Ahmadi, Oluwole Alfred Olatunji	Curtin University (Australia)	Knowledge management in marine projects through value engineering protocols, a review
11:10	Paper 4	**Arka Ghosh**, M. Reza Hosseini	Deakin University (Australia)	Internet of Things – Optimizing Opportunities in the Australian Construction Industry
11:30	Paper 5	**Hongyu Jin**, Dr Chunlu Liu	Deakin University (Australia)	Optimal concession period design to cope with uncertainty in public-private partnerships
11:50	Keynote 1	Dr Igor Martek	Deakin Univerisity	Large Infrastructure Delivery: International Construction
12:15	**Lunch + Networking**			
13:00	Keynote 2	Dr M. Reza Hosseini	Deakin University	Getting Published
13:30	Keynote 3	Dr Ajibade Aibinu	University of Melbourne	Getting the most out of the PhD process: navigating the challenges of undertaking a PhD
14:00	Paper 6 (LiveCast from UK)	**Benito Mignacca**, Dr Giorgio Locatelli	Leeds University (UK)	Linking circular economy and modularisation in energy infrastructure: state of the art and a way forward
14:20	Panel Q&A	Dr Ajibade Aibinu, Dr Igor Martek, Dr Reza Hosseini	Surviving the PhD Process & Publication Process	
14:50	**Networking + Afternoon Tea**			

OPTIMAL CONCESSION PERIOD DESIGN TO COPE WITH UNCERTAINTY IN PUBLIC-PRIVATE PARTNERSHIP

Hongyu Jin and Chunlu Liu

Deakin University, Geelong, Australia, School of Architecture and Built Environment, Faculty of Science, Engineering and Built Environment.

Public-private partnership (PPP) has been widely used in delivering infrastructure projects, such as freeway, tunnel and bridge. One of the most important parameters in PPP contract that needs to be predetermined is the concession period. Formulation of the length of the concession period should consider not only the profits of the private investors, but also the influence of the concession period in risk control. This paper develops a concession period determination model based on expanded net present value and bargaining game theory. It is also considered that the influence of the risk preferences held by project parties on the length of the concession period. Additionally, the financial risks borne by both parties are measured to verify the risk control ability of the concession period. Refer to a real PPP project in Australia, project BA is created as a numerical example to verify the proposed method. The outcome shows that the project parties can create a win-win situation during the optimized concession period and that the probability of suffering risk events for both parties is controlled within the acceptable range. The decision process used in this paper demonstrates strong effectiveness and ability to determine the optimal length of a concession period.

Keywords: concession period; public-private partnership; real option; risk control

INTRODUCTION

Public-private partnership (PPP) is defined as “a long-term contractual arrangement between the public and the private sector to realize public infrastructure and services more cost effectively and efficiently than under conventional procurement” (Daube et al., 2008). In the past decades, PPP has gained popularity in delivering infrastructure projects with a long-term relationship between clients and contractors due to its ability to alleviate government financial pressure (Zou et al., 2014). The broad application of PPP schemes provides the incentive of pursuing a management strategy that can increase the project efficiency in time and cost for concessionaries. Scholars doing research on PPP-related topics address the following issues. First, the market risks during the concession period need to be handled and some scholars have tried to achieve a fair risk allocation between project participants (Hwang et al., 2013). Second, it is important to find a way to mobilize social capital participation (Liu et al., 2016). Third, if the market surroundings fluctuate to an unfavourable position or there is force majeure, the way to facilitate social capital exit while minimising the influence on governments is still an open question (Nuer, 2015). However, the premise in analysing all these problems is to determine the specific attributes value of the PPP project, e.g. concession pricing, concession period and minimum revenue guarantee.

This paper focuses on the determination methodology for the length of the concession period. The concession period as one of the most important parameters is usually set as a default that is the same length as in similar projects (Song et al., 2015) or decided just based on the experts' experience (Khanzadi et al., 2012). However, these practices tend to encourage project early termination, since they neglect the fact that market surroundings can be significantly different in different projects, which implies that the concession period should be decided independently even for similar projects. This research aim to find a method that can calculate the optimal concession period considering conditions of the market environment. The aim in determining the concession period is to achieve risk control between governments and private investors and ensure that the private investor can gain its expected investment return under the limitation of the revenue cap set by the governments.

Many concession period models are designed following the principle that the concession period should be long enough to guarantee that the private investors can reclaim their money through revenue in the operational stage. Hence, net present value (NPV) estimation is used to construct the core of these models. For example, Hanaoka and Palapus (2012) calculated the concession period based on the NPV for two build-operate-transfer road projects and used the Monte Carlo simulation as well as bargaining game theory to find the optimal project transfer point. Carbonara et al. (2014) developed a win-win model to take government profit into consideration. However, NPV analysis tends to neglect the option value of the project. The project manager holds the right to make decisions on the project activities and the decision choices create different types of option values for the project. Previous studies showed that the range of option values can be enormous and can affect investment decisions (e.g. Yeo and Qiu, 2003). This research reviews the capital existence opportunity as an abandonment option to see if the option value can influence the length of the concession period. Because only a few pieces of research test the effectiveness of their models in risk control, and none of them consider the influence of risk preference on the agreement on the length of the concession period, this study fills the gap in designing a concession period determination method based on the fair risk preferences of the project participants, as well as providing a method of risk verification.

RESEARCH BACKGROUND

NPV-based concession period design

NPV analysis requires figuring out the amounts of the cash inflow and cash outflow of a project on the side of the contractors. For a PPP project, the cash outflow covers the construction cost, the operation and maintenance cost, and other implicit costs, like negotiation costs, the cost of the land acquisition, and so on. The contractor can pay the construction cost as a lump-sum payment or pay individually according to the building process. The operation and maintenance fee is usually paid annually to maintain the operation of the project. The contractor starts to receive cash inflow when the project opens to the public. Hence, the NPV of a PPP project is found through Eq. (1):

$NPV_p = R - I_c - I_i$ (1)

where $R = \sum_{t=t_0}^{n} \frac{R_t - I_{O\&M_t}}{(1+r)^t}$, $I_c = \sum_{t=0}^{t_0} \frac{I_{c_t}}{(1+r)^t}$. R is the revenue earned in the operational stage. I_c is the overall construction cost. I_i indicates other initial investment. R_t is the revenue from operating the project at year t. $I_{O\&M_t}$ is the operation and maintenance cost at year t. n is the lifetime of the project. t_0 is the instant of time when the project opens to the public. r is the discount rate. I_{c_t} is the yearly construction cost at year t.

After clarifying the profitability of a project through NPV analysis, both private investors and governments want to know how much money will be earned during their operational stages, i.e. the concession period and post-transfer stage respectively. Predetermined parameters, like concession pricing and the concession period, need to be negotiated in the pre-construction stage. Private investors start receiving revenue when the project opens to the public and the governments earn money after the project is transferred from the private investors. Thus, the concession period, or in other words the length of time after which the project should be transferred from private investors to public parties, is an important contractual parameters that needs to be decided. Several methodologies are derived from NPV analysis for calculating the value of the optimal concession period, and the core of these methodologies is to define the boundaries of the private investors' revenue (Carbonara et al., 2014; Hanaoka and Palapus, 2012; Zhang, 2009). Since private investors want to earn a profit that is at least higher than the minimum return on investment that they could accept, the lower revenue limit is defined as shown in Eq. (2):

$$NPV_c \geq (I_c + I_i) \times ROI_{min} \quad (2)$$

where NPV_c is the cumulative net present value for private investors during the concession period, whose value can be indicated as $\sum_{t=t_0}^{t_e} \frac{R_t - I_{O\&M_t}}{(1+r)^t}$. t_e gives the instant of time when the concession period ends. ROI_{min} is the private investors' expected minimum return on investment. In terms of the principle that an investment decision only can be made when the expected revenue exceeds the opportunity cost, the value of ROI_{min} should be around the profit rate of a similar project.

On the other hand, the governments have the intention to control the private investors' profit within a reasonable range, so they define an upper revenue limit for private investors as shown in Eq. (3):

$$NPV_c \leq (I_c + I_i) \times ROI_{max} \quad (3)$$

where ROI_{max} is the maximum return rate allowed by the government to the private sector. $ROI_{\max}$ is usually decided during the pre-construction negotiation stage so as to avoid overly lucrative conditions for private investors. The sole independent variable in Eq. (2) and Eq. (3) is the length of the concession period. As shown in Figure 1, through solving these two inequalities, the minimum and maximum lengths of the concession period are produced. The project parties should settle the concession period within the range of $[t_{cmin,} t_{cmax}]$.

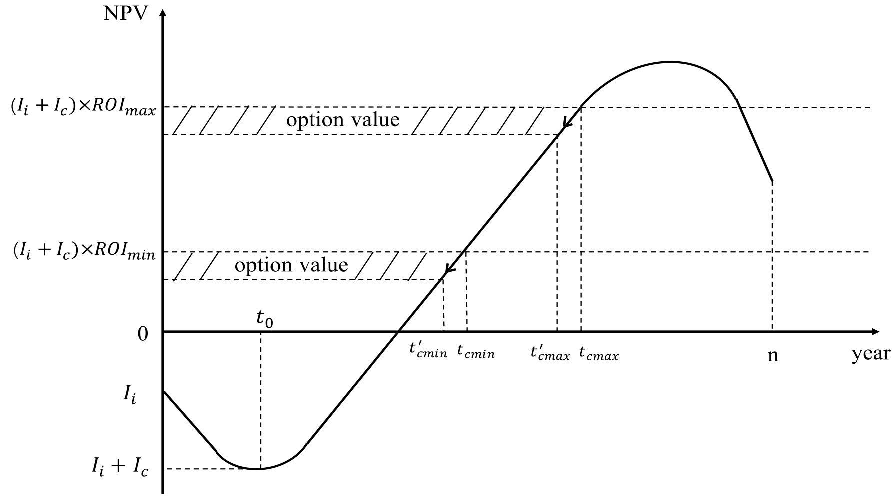


Fig. 1 The determination of the concession period scope based on NPV analysis

Real options in PPP projects

The NPV method cannot adequately reflect the value of uncertainties in a project, which may lead to a fatal investment decision (Trigeorgis and Reuer, 2017). Even though some parameters, like traffic volume, can be measured in a stochastic way, the value of 'rights' embodied in the project is still waiting to be uncovered in traditional NPV analysis. Leviäkangas and Lähesmaa (2002) argued that NPV analysis cannot grasp all uncertain variables in a transport infrastructure project. However, real options analysis provides a way to evaluate the 'rights' offered by uncertainties and tries to reflect the true value of a project in dynamic market surroundings (Dixit and Pindyck, 1994). Real options analysis has been widely used in the field of PPP project management, as it allows for calculating the value of flexibilities in the lifecycle of PPP projects.

The private investors may hold different kinds of option rights during the operational stage. The option to expand means that if the market surroundings are experiencing an upward trend and the project is carried out in stages, the value added could come from the expansion opportunities in the future (Cheah and Garvin, 2009). The option to delay is produced when the project manager decides to delay the project to receive more market information, but sometimes the cost of delaying a project is also high (Kremljak et al., 2014). In most countries carrying out PPP projects, the exit mechanism for the project is specified in the contract documents and protected by the law of the land (Bulnina et al., 2015). Hence, the project investors hold the option to abandon, which means that if the market surroundings go into extremely unfavourable conditions, they could choose to quit and receive a certain amount of money in return.

There are two main real-options pricing models. One is the binomial lattice model whose basis is the discrete random walk, and the other one is the Black-Scholes pricing model. The binomial lattice model assumes that there are two directions for unstable variables to move: upward or downward. If the variable moves up, the value in the next stage should be the initial value multiplied by the quotient (u) and otherwise, multiplied by the quotient (d), and the probability of moving up is expressed as (p), where $u =$

$e^{\sigma'\sqrt{\Delta t}}$ $, d = e^{-\sigma'\sqrt{\Delta t}}, p = \frac{e^{r'\Delta t} - d}{u - d}$ (Hull, 2010). σ' is the volatility of underlying assets. Δt is the step interval. r' is the risk-free rate. The main strength of the binomial lattice model is that the option execution point can be easily observed in a tree chart. However, if the project has a long lifecycle or short step intervals, the calculation of the binomial lattice model becomes complicated and it is hard to display the tree chart with large branches. In this case, the Black-Scholes pricing model is more practical.

The real option value in highly unstable surroundings can be a huge number. Smit and Trigeorgis (2012) stated that the sum of NPV and option value equals the value of expanded NPV (ENPV), which can reflect the value of a project's flexibility. In this research, ENPV analysis is adopted to predict the future cash inflow for the private investors instead of NPV. The concession period decision scope should change downward, as shown in Figure 1, and the concession period interval is expected to change from $[t_{cmin,} t_{cmax}]$ to $[t'_{cmin,} t'_{cmax}]$, which is a neglected part of many other studies.

OPTIMAL CONCESSION PERIOD DETERMINATION PROCESS

In this part, an optimal concession period determination process is proposed, which contains the following steps: First, based on the project background, the Geometric Brownian motion (GBM) paths for uncertain variables in the project are simulated and ENPV for private investors as well as NPV for the governments are calculated. Second, according to the calculation results, the decision range of the concession period is determined to see, when the value of the real options is taken into consideration, to what extent the concession period decision range changes in an ENPV analysis. The optimal concession period during which both governments and private investors can achieve a win-win situation is also determined at this stage. Third, the financial risks are calculated to see if they can be controlled for both parties within the scope of the designed concession period. A risk verification process is set up to highlight the principle that the concession period determination should help to achieve not only fair revenue allocation, but also life-cycle risk control. Finally, a model for transferring the risk between the project participants based on their risk preferences is proposed. The overall flow chart of the optimal concession period determination process can be seen in Figure 2. The models mentioned in the process, i.e. concession period bargaining model, risk verification model, and risk transfer model, are illustrated afterwards.

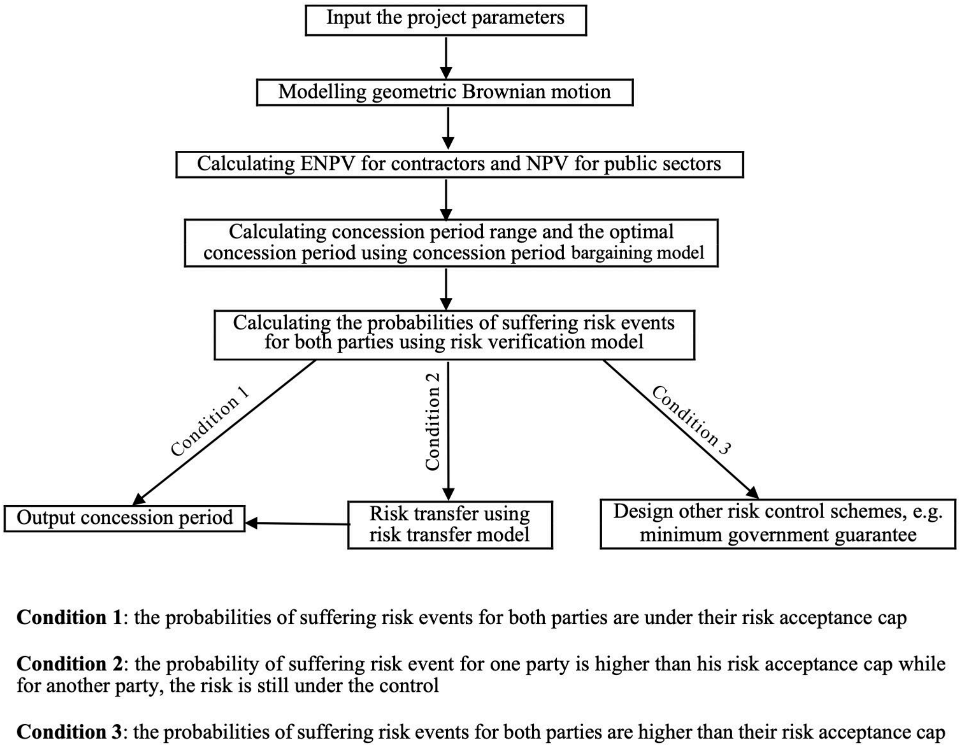


Fig. 2 The optimal concession period decision process

Concession period decision range and a bargaining model

After ENPV analysis for private investors, the concession period decision range can be produced. According to the principle that private investors expect to gain more profit through the project than the expected minimum return on investment, the lower limit of the concession period (t'_{cmin}) is decided by Eq. (4):

$$t'_{cmin} = \min\{t_c : F_1(t_c) = ROc(t_c) + NPVc(t_c) - (I_c + I_i) \times ROI_{min} \geq 0\} \quad (4)$$

where $F_1(t_c)$ is the function of the profit premium for private investors. $RO_c(t_c)$ is the value of real options that private investors hold within the period t_c, which can be derived from the binomial lattice model or the Black-Scholes pricing model. $NPVc(t_c)$ is the NPV value for private investors within the period t_c. t'_{cmin} equals the minimum value of t_c obtained from $F_1(t_c)$. No moment before this threshold will be accepted by private investors, since they cannot receive the expected minimum return on investment within that period.

The upper limit of the concession period (t'_{cmax}) is calculated by Eq. (5):

$$t'_{cmax} = \max\{t_c : F_2(t_c) = ROc(t_c) + NPVc(t_c) - (I_c + I_i) \times ROI_{max} \leq 0\} \quad (5)$$

where $F_2(t_c)$ is the function of the difference between the profit earned for private investors and the revenue cap. t'_{cmax} equals the maximum value of t_c obtained from $F_2(t_c)$. No moment after this threshold will be accepted by the governments, as the private investors can earn excess profit in an overly long period. Moreover, a prolonged concession period squeezes the time during which the governments receive revenues. Every instant of time located within the interval of $[t'_{cmin,} t'_{cmax}]$ can fulfil the profit requirement of private investors, and meanwhile the governments achieve the target of limiting private investors' revenue within a reasonable range.

The optimal length of the concession period is calculated following a three-stage bargaining process. As shown in Figure 3, in the first stage of the bargaining process, the private investor offer a concession period of t_{c1}. If the government accept the offer, they will gain the payoff whose value equals the extra money they can claim from the private investor for a profits control. The payoff for the private investor will be the money earned that is higher than their opportunity cost. The game will ends in stage three whether the government accepts the counteroffer proposed by the private investor or not. The private investor will offer t'_{cmax} to maximize their payoff at the final stage.

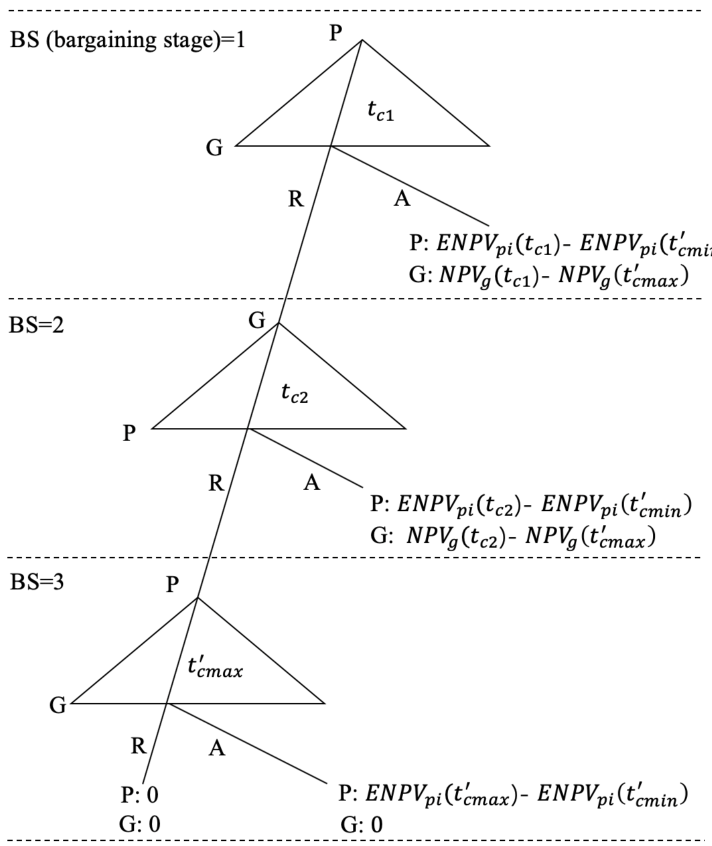


Fig. 3 A three-stage bargaining process

The optimal length of the concession period can be derived via a backward induction. In stage 2, in order to make it no difference for the private investor to accept or reject the offer, the value of t_{c2} should meet the following equation:

$$ENPV_{pi}(t_{c2}) - ENPV_{pi}(t'_{cmin}) = \sigma_{pi} \times [ENPV_{pi}(t'_{cmax}) - ENPV_{pi}(t'_{cmin})] \quad (6)$$

where σ_{pi} is the discount factor for the private investor.

Similarly, the value of t_{c1} meets:

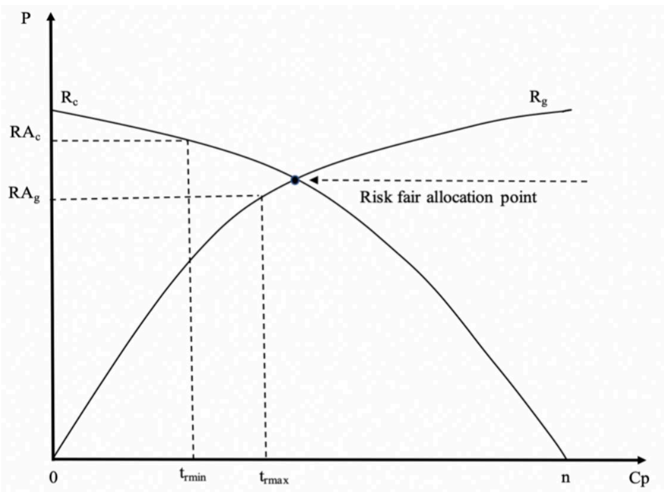
$$NPV_g(t_{c1}) - NPV_g(t'_{cmax}) = \sigma_g \times [ENPV_{pi}(t_{c2}) - ENPV_{pi}(t'_{cmax})] \quad (7)$$

where σ_g is the discount factor for the government. By importing the value of t_{c2} derived from the Eq. (6), the value of t_{c1} can be obtained. The optimal length of the concession period equals t_{c1} as when the private investor propose t_{c1} in the first stage, the bargaining game can reach its equilibrium point.

The optimal concession period is calculated at this stage. However, the forecast traffic volume can show various fluctuating trends in different simulation paths, so the optimal concession period based on our predicting path may fail to control the risk of loss in other simulation paths. Thus, a risk verification model is designed to verify the ability of the optimal concession period for risk control.

Risk verification model

Before proposing the risk verification model, it is important to understand the relationship between the length of the concession period and the probabilities of suffering risk events for the project parties. With an increase in the length of the concession period, the probability of suffering risk events for private investors is expected to decrease, since they have more time to earn money. However, for the governments the probability value shows the opposite trend. It can be seen from Figure 4 that if the governments and private investors have high risk tolerance, there will be a new concession period interval produced based on their risk preferences. If the concession period determined before, i.e. t_{opt}, is located in the interval of $[t_{rmin}$, $t_{rmax}]$, the effectiveness of the designed concession period in risk control can be shown. Otherwise, there will be only one party that can achieve the goal of controlling risk. Nevertheless, it is also possible that both private investors and governments have low risk tolerance, e.g. their risk tolerance caps are lower than the fair risk allocation point. In this case, a concession period interval based on the risk preferences cannot be produced and the risk for both parties cannot be controlled through designing an optimal concession period.



RA_c: risk acceptance cap for private investors; RA_g: risk acceptance cap for governments; R_c: risk borne by private investors; R_g: risk borne by governments; t_{rmin}: minimum concession period based on risk preference; t_{rmax}: maximum concession period based on risk preference; n: project lifespan; p: the possibility of suffering risk events; Cp: the length of the concession period.

Fig. 4 Risk preference and the value of the concession period

A risk verification model, which carries out 1000 times path simulation, is proposed to verify the effectiveness of the determined concession period in risk control for other simulation paths. By assuming the distribution of the uncertain variables, i.e. GBM in this research, the probability of risk occurrence can be calculated. Then the revenue path over the whole project lifetime can be generated to calculate the occurrence rate of risk events of the 1000 times simulation path for private investors in the designed concession period and for governments in the post-transfer stage. The possibility of suffering risk events for both parties should not exceed their risk acceptance caps. The risk verification function is shown below:

$$\begin{cases} P\left[ENPV(t_{opt}) < (I_c + I_i) \times ROI_{min}\right] \leq RAc \\ \qquad P\left[NPV_g(t_{opt}) < 0\right] \leq RAg \end{cases} \quad (8)$$

where

$$P\left[ENPV(t_{opt}) < (I_c + I_i) \times ROI_{min}\right] = \frac{countif\left[ENPV_i^m(t_{opt}) < (I_c + I_i) \times ROI_{min}\right]}{m} \quad i = 1 \cdots m\,;$$

$$P\left[NPV_g(t_{opt}) < 0\right] = \frac{countif\left[NPVg_i^m(n - t_{opt}) < 0\right]}{m} \quad i = 1 \cdots m\,.$$

RAc and RAg are the risk acceptance caps for private investors and governments respectively. m is the number of simulation times, which is 1000 in this research. i indicates the sequence of the simulated GBM path. The value of t_{opt} need to be verified to see whether it meets the requirement of the two prerequisites shown in Eq. (8). If the optimal concession period fails to pass the verification, the optimal concession period can be revised according to the risk preferences that project parties hold.

Risk transfer model based on project participants' risk preferences

The risk verification process can produce difference outcomes. The best case would be that the proposed concession period can control risk occurrence rates for both parties under their risk acceptance caps while creating a win-win situation. If the concession period determined through the concession period bargaining model leads to a risk occurrence rate that is higher than the risk capacity of both parties, the designed concession period will not play a role in risk control. If only one party suffers a risk spillover, the final concession period will be decided by their risk preference. Thus, a risk transfer model is designed to cope with this condition. For better explanation, it is assumed that there is a risk holder 1 who suffers more risk than their risk capacity. Risk holder 1 wants to transfer the excess risk to risk holder 2, who suffers less risk than their risk capacity. During the risk transfer process, the concession period needs to be adjusted to achieve this risk re-allocation. The new concession period after the risk transfer process can be found following Eq. (9):

$$t_{cnew} = \{t_c : F_3(t_c) = R_1 - RA_1 + R_2 - P_2(t_c) = 0\} \quad (9)$$

$$s.t.\, R_2 + R_1 - RA_1 \leq RA_2$$

where R1 is the risk borne by risk holder 1. R2 is the risk borne by risk holder 2. RA1 and RA2 are the risk acceptance caps of risk holder 1 and 2 respectively. t_{cnew} is the revised concession period after transferring the risk. $P_2(t_c) = P\{[ENPV' < (I_c + I_i) \times$

$ROI_{min}] \vee [NPV_g{}' < 0]\}$ is the occurrence rate of the risk events that risk holder 2 holds. The constraints show the principle that the risk held by risk holder 2 is still under the risk acceptance cap after the risk transfer process.

NUMERICAL EXAMPLE

The proposed determination method is applied to Project BA to verify its applicability. Conducted as a freeway PPP project, the estimated construction cost is 4.8 billion Australian dollars. The road is toll free for the first three months, and afterwards the toll charge is 2.5 Australian dollars per vehicle for the following 10 months. After a 13-month trial period, and the toll is kept at 4.9 Australian dollars.

Concession period determination

Initially, it is necessary to clarify the project parameters that are used in the determination model. Some of the project parameters show uncertainty, as they change with the trends of the market surroundings. These parameters are given as follows: the initial yearly traffic volume forecast for the Brisbane airport link is 1.10×10^8. The volatility of the future traffic volume is 12.5%. The operational cost is assumed to be 0.8 Australian dollars per vehicle before the full charge of the toll road. Afterwards, the annual operational cost is set at 30% of the annual toll revenue. The maintenance cost is 4 billion Australian dollars in the initial year with a 3% annual growth rate according to the local consumer price index. The expected traffic growth rate of the Project BA is in line with the local yearly traffic growth rate of 2.9%. Since the decision model calculates the cash flows based on the randomly traffic volume. The discount rate used for calculating the project NPV is the risk-free rate, which is 2.6% that equals the 10-years yield of the Australia bond. The underlying asset value for the real options calculation equals the NPV value for the first operational year, which is 9.55×10^6 Australian dollars.

In addition to the uncertainty parameters, the project itself has some inherent attributes: the construction period is 4 years, and the project life is 60 years. The construction cost is 4.8 billion, and it is assumed that there are no other transaction costs during the project lifecycle. The minimum return rate on investment is 10%, and the maximum return rate on investment allowed by the government is 20%. Both the private investor and governments can only tolerate a risk probability of less than 10%. The traffic volume simulation path can be produced via Eq. (10):

$$T_{t+1} = T_t \times e^{\left(\mu_T - \frac{\sigma_T^2}{2}\right)\Delta t + \sigma_T \varepsilon \sqrt{\Delta t}} \quad (10)$$

where T_t indicates the current traffic volume and T_{t+1} is the traffic volume in the next year. Δt is the year used for data analysis. μ_T is the expected traffic growth rate during Δt. σ_T is the annual volatility of the traffic volume accordingly.

Based on the generated GBM path, the ENPV value for the private investors can be calculated. What should be noted here is that the real option considered in this project is the abandonment option (viewed as an American put option). It is assumed that the project manager holds the right to quit the project once the traffic volume is 30% lower than the expected volume in the initial year. Therefore, the executive price of the option is 70% of the value of the underlying asset (i.e. traffic revenue). Since the Black-Scholes pricing model cannot be used for American options pricing, the binomial tree method is adopted, and the calculation outcome shows that the real option value is 167,240 Australian dollars over the whole project lifecycle.

By applying the concession period decision model, the minimum length of the concession period is calculated as 41 years, and the maximum length is 45 years, which means that the concession period should be located in the interval of 41 to 45 years. Given $\sigma_{pi} = \sigma_g = 0.98$, the optimal concession period decided is 45 years during which a win-win situation can be created.

Risk verification

Figure 5 indicates that the probability of suffering loss from the project each year is less than 8%, which illustrates that the project itself has a low-risk inclination and provides a reason that the value of the abandonment option is so small. Next, a 1000 times path simulation is run to see the applicability of the designed concession period in risk control. The risk control ability of the designed concession period is measured via the risk verification model. The outcomes show that the possibilities of suffering risk events for private investors within the concession interval of 41 to 45 years are 4.6%, 4.2%, 4.5%, 3.6%, and 3.3% respectively, while for the governments at the post-transfer stage the percentages are 1.7%, 2.0%, 1.6%, 1.7%, and 2.3% respectively. The results of the risk verification process show that all the concession periods located in the interval are found to be eligible to control both parties' risk within 10%. Since the possibilities of suffering risk events for both parties are within their risk acceptance caps, the risk transfer process is not needed for this project. Hence, the optimal concession period is kept at 45 years.

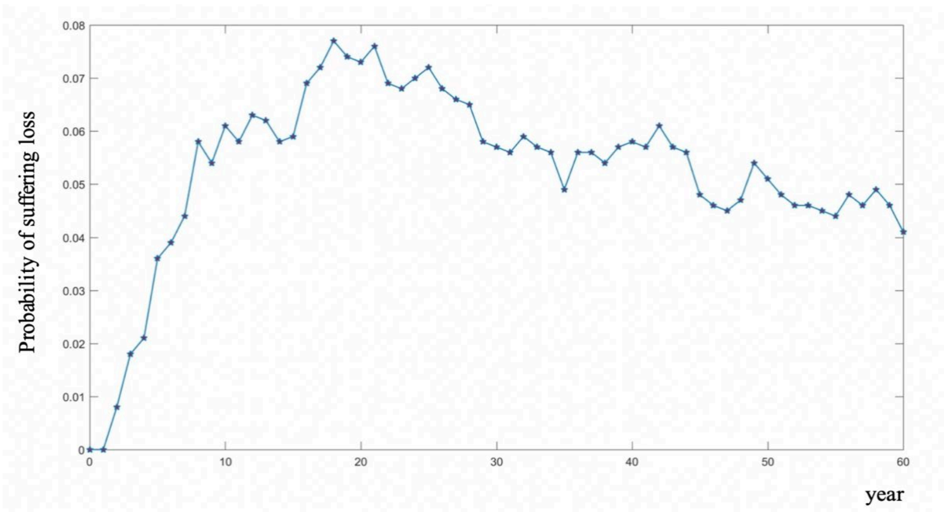


Fig. 5 The probability of suffering loss at each step interval

CONCLUSION

One of the keys to the successful operation of PPP projects is to determine the concession term properly. Previous models paid too much attention to the profitability of private investors while neglecting the capacity of the concession period in risk control. This research proposes an optimal concession period determination method aiming to create a win-win situation between private investors and governments as well as control the financial risk for both parties. Expanded NPV analysis is adopted ton reflect the income for the private investors more accurately. Through the risk verification process, 1000 times GBM paths of uncertain variables are generated. If the risk probability for one party exceeds their risk tolerance range while the risk for the other project party is still under control, the risk transfer model is designed to transfer the risk under this condition.

The Project BA is used as a numerical example to justify the proposed model. By passing through the concession period determination process, the optimal concession period is decided during which the private investor can earn higher than their expected return on investment while under the revenue control of the government. Additionally, the risk of deficit for each party is controlled to be under 10%. The application shows that the designed models are effective tools for PPP projects in the decision-making of the length of the concession period.

The real option chosen in this research is the option to abandon, but the analysis shows that there is no change in the concession period threshold whether the real option value is accounted for or not. This outcome may arise from the relatively small value of the abandonment option. However, there are many other real options embodied in PPP projects, and this paper cannot cover them all. An assumption that can be made here is that a project with a positive growth rate may involve a non-ignorable value of the expansion option, especially when the project operates in stages. Future research could focus on this and figure out the influence of the expansion option on the concession period thresholds.

REFERENCES

Banister, D., 2005. Unsustainable transport: city transport in the new century. London, UK: Taylor & Francis.

Brandao, L. E. T., Saraiva, E., 2008. The option value of government guarantees in infrastructure projects. Construction Management and Economics, 26(11), 1171-1180.

Bulnina, I., Askhatova, L., Kabasheva, I., Rudaleva, I., 2015. Public and Private Partnership as a Mechanism of Government and Business Cooperation. Mediterranean Journal of Social Sciences, 6(1 S3), 453.

Carbonara, N., Costantino, N., Pellegrino, R., 2014. Concession period for PPPs: A win–win model for a fair risk sharing. International Journal of Project Management, 32(7), 1223-1232.

Cheah, C. Y., Garvin, M. J., 2009. Application of real options in PPP infrastructure projects: opportunities and challenges. Policy, Finance & Management for Public-Private Partnerships. Wiley-Blackwell, 229-249.

Daube, D., Vollrath, S., Alfen, H. W., 2008. A comparison of Project Finance and the Forfeiting Model as financing forms for PPP projects in Germany. International Journal of Project Management, 26(4), 376-387.

Dixit, A. K., Pindyck, R. S., 1994. Investment under uncertainty. Princeton, USA: Princeton university press.

Hanaoka, S., Palapus, H. P., 2012. Reasonable concession period for build-operate-transfer road projects in the Philippines. International Journal of Project Management, 30(8), 938-949.

Hull, J., 2010. Options, Futures, and Other Derivatives, 7/e (With CD). Delhi, India: Pearson Education India.

Hwang, B.-G., Zhao, X., Gay, M. J. S., 2013. Public private partnership projects in Singapore: Factors, critical risks and preferred risk allocation from the perspective of contractors. International Journal of Project Management, 31(3), 424-433.

Irwin, T., 2003. Public money for private infrastructure: deciding when to offer guarantees, output-based subsidies, and other fiscal support. Washington, USA: World Bank Publications.

Khanzadi, M., Nasirzadeh, F., Alipour, M., 2012. Integrating system dynamics and fuzzy logic modeling to determine concession period in BOT projects. Automation in Construction, 22, 368-376.

Kremljak, Z., Palcic, I., Kafol, C., 2014. Project evaluation using cost-time investment simulation. International Journal of Simulation Modelling, 13(4), 447-457.

Laffont, J.-J., Martimort, D., 2009. The theory of incentives: the principal-agent model. Princeton, USA: Princeton university press.

Leviäkangas, P., Lähesmaa, J., 2002. Profitability evaluation of intelligent transport system investments. Journal of Transportation Engineering, 128(3), 276-286.

Liu, J., Gao, R., Cheah, C. Y., Luo, J., 2016. Incentive mechanism for inhibiting investors' opportunistic behavior in PPP projects. International Journal of Project Management, 34(7), 1102-1111.

Nuer, A. T. K., 2015. Exit strategies for social venture entrepreneurs. Wageningen, Netherlands: Wageningen University.

Smit, H. T., Trigeorgis, L., 2012. Strategic investment: Real options and games. Princeton, USA: Princeton University Press.

Song, J., Song, D., Zhang, D., 2015. Modeling the concession period and subsidy for bot waste-to-energy incineration projects. Journal of Construction Engineering and Management, 141(10), 04015033.

Trigeorgis, L., Reuer, J. J., 2017. Real options theory in strategic management. Strategic Management Journal, 38(1), 42-63.

Vega-Redondo, F., 1996. Evolution, games, and economic behaviour. Oxford, UK: Oxford University Press.

Yeo, K., Qiu, F., 2003. The value of management flexibility—a real option approach to investment evaluation. International Journal of Project Management, 21(4), 243-250.

Zhang, X., 2009. Win–win concession period determination methodology. Journal of Construction Engineering and Management, 135(6), 550-558.

Zou, W., Kumaraswamy, M., Chung, J., Wong, J., 2014. Identifying the critical success factors for relationship management in PPP projects. International Journal of Project Management, 32(2), 265-274.

IMPEDING FACTORS FOR BUILDING INFORMATION MODELLING ADOPTION IN FACILITIES MANAGEMENT

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In the last few years, Building information modelling (BIM) has achieved a paradigm shift and proven benefits in the whole project lifecycle including facilities management (FM). Despite, BIM adoption is still facing some risks and challenges especially in FM phase. This study investigates the impeding factors of BIM adoption in Australia, where BIM is fairly new to FM phase of the project and needs more focus and attention. Thus, a questionnaire survey was administrated to both public and private sector participants in Australia in order to identify the importance of those impeding factors. 134 respondents provided valid responses out of about 300 questionnaire forms sent out. Based on the collected data, the relative importance of 17 impeding factors for BIM in FM is examined. The results from the data analysis reveal that the three most important factors are (1) Unknown FM data requirements, (2) Lack of FM team participation in the design phase, and (3) Timeliness training before hand-over stage. The findings of this study are expected to provide a better understanding of the essential barriers of BIM adoption in FM context, and guide the industry stakeholders in developing proper strategies for effective management of the BIM adoption process in FM.

Keywords: BIM, Facility Management, Impeding Factors, Barriers, Adoption

INTRODUCTION

Recent research has revealed that the emergence of BIM has successfully achieved a significant benefits in all project's phases. However, the real focus is still very high on the design and construction phases. Thus, it has been concluded that the adoption of BIM in FM is still only minimal. Researchers stated " Even most large public owners who have been early adopters of BIM, such as GSA, USACE or Senate Properties, have used BIM more in managing their construction projects than implemented it into their

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FM activities" (Kiviniemi and Codinhoto, 2014). They argues that this situation might be changing because UK Government's has included more BIM requirements such as the delivery of electronic asset information. These new requirements have added a global effects in the merit of BIM as an efficient tool for FM systems and practices. Accordingly, this study aims at identifying the impeding factors of BIM adoption in FM.

LITERATURE REVIEW ON BIM ADOPTION IN FM

Overall, the research to date suggests that the construction industry and FM have benefited from BIM adoption in a way that reshapes the industry itself. For example, Becerik-Gerber et al. (2012) show how the use of BIM has been extended to include the operation and maintenance phase in terms of locating building components, facilitating real-time data access, visualization and marketing, checking maintainability, space management, planning and feasibility studies for noncapital construction, emergency management, controlling and monitoring energy, and personnel training and development. Thus, a project's lifecycle integration in terms of project phases has become more reliable and requires a new way of project delivery. Brooks and Lucas (2014) identified key factors for success in streamlining BIM use in post-construction and show how BIM can benefit the contractor. Their study aimed to bridge the gap between the owner and contractor and resulted in the development of a framework that helps the contractor in the hand-over process in the post-construction stage. Similarly, Kassem et al. (2015) performed a case study to explore the benefits and challenges of BIM in facilities management at Northumbria University campus. The results showed that BIM benefits to facilities management arise from enhancement of current paper-based handover processes, improve the level of accuracy of required data, and facilitate the accessibility of data and efficiency in work order procedures. They also noted the following challenges:

- The lack of methodologies that demonstrate the tangible benefits of BIM in FM.
- The limited knowledge of implementation requirements
- The presence of disparate operational systems managing the same building.
- The shortage of BIM skills in the facilities management industry.

In regard to facilities management activities, Arayici et al. (2012) showed how BIM can support the efficient and effective implementation of facilities management activities using the university building in MediaCityUK as a case-study. These benefits were summarized as follows:

- Walkthroughs generated from the BIM model offer virtual tours to visually assess key considerations during relocation.
- Automated quantification and scheduling capability help in setting cost and time targets such as the development and confirmation of budget.
- Accurate quantification and scheduling attribute provide detailed information on number and types of furniture to be moved and another cost intensive decision-making considerations.

Volk et al. (2014) reviewed over 180 publications on BIM. They concluded that there is a scarcity of research in BIM implementation for existing buildings. They emphasized that this scarcity is due to:

- The effort of conversion from as built building data into BIM objects
- Information updating in BIM
- Dealing with uncertain data, relations and objects in BIM in existing buildings.

Their study has raised the attention to the existing building which form the most percentage of the construction projects sector, and this may help to enhance the FM sector by implementing BIM. Yalcinkaya and Singh (2014) have reviewed 87 papers in the area of BIM in FM using different data base sources. They found that there is a great value and potential benefits of BIM in FM. Those benefits include; automated the whole project life cycle information including the operation and maintenance phase and optimization of project's cost and time using real-time access for non-graphical and data graphical. Also, they revealed some challenges that face the adoption of BIM in FM such as:

- Interoperability between FM systems and BIM
- Unclear implementation of BIM in FM through early project's stages
- Importing of as-built information of the facilities to BIM model.
- Lack of information exchange frameworks like COBie to solve data transfer issues.

Gao and Pishdad-Bozorgi (2019) emphasized that adoption of BIM-FM systems is still hindered by several factors such as the interoperability between BIM and FM context, understanding the implied FM principles for BIM adoption, and cost-value issues. The author suggested possible starting point to address the interoperability issue in the BIM-FM context is by adopting the National Institute of Standards and Technology (NIST) Cyber throughout the Physical Systems (CPS) model. Also, he concluded that more studies including surveys are needed to understand the principles for BIM adoption in FM. Dixit et al. (2019) addressed 16 issues based on literature review of 54 research under the four categories of BIM execution and information management, cost-based and legal, technological and contractual issues. The survey results' of FM professionals with 57 complete responses revealed that the most key issue is the lack of FM professionals' engagement in early project phases when BIM is developing. Barbarosoglu and Arditi (2019) proposed a maintainability checking system algorithm which can be specified for all building elements, and it can be compatible with BIM tool such as Revit. The emphasized that BIM can reduce the gap between the design and facilities management without increasing the load of designers. This can be done by allowing designers to design in a way that improves the FM issues at the design phase itself.

Miettinen et al. (2018) identified the gap between BIM adoption in design and in FM. Premises Centre of the City of Helsinki key professional experts of FM were interviewed to discuss the information tools being used in their centre, and the needs and impediments of BIM adoption in the FM. The emphasised that the challenges in the BIM adoption are in which ways the relevant data and information included in BIM models could be integrated with FM systems.

Becerik-Gerber et al. (2012) has classified a number of technological and organizational challenges for BIM in FM as following:

1. Technology and process related challenges:

- Unclear roles and responsibilities for loading data into the model or databases and maintaining the model;
- Diversity in BIM and FM software tools, and interoperability issues;
- Lack of effective collaboration between project stakeholders for modelling and model utilization;
- Necessity yet difficulty in software vendor's involvement, including fragmentation among different vendors, competition, and lack of common interests

2. Organizational challenges:
- Cultural barriers toward adopting new technology;
- Organization wide resistance: need for investment in infrastructure, training, and new software tools;
- Undefined fee structures for additional scope;
- Lack of sufficient legal framework for integrating owners' view in design and construction;
- Lack of real-world cases and proof of positive return of investment.

In addition, one of the most challenges in implementing BIM in the FM practises is that most of organisations have their own FM systems and software platforms to manage the FM information. New buildings are very small portion of the already existing buildings, and this situation raises many questions related to challenging the change (Kiviniemi and Codinhoto, 2014).

Briefly, BIM helps support functions of facilities management by its analysis tools, visualization capabilities and provision of initial information to facilities management systems. Although many experts and researchers are in agreement about the potential benefits of BIM in FM, there is still considerable uncertainty about how to use BIM efficiently and to what extent BIM can help solve facilities management problems (Lee et al., 2012). Hence, the impeding factors of BIM-FM remains a significant concern of BIM practice and research.

Overall, studies in the literature primarily focus on BIM adoption especially in qualitative manner by using specific case studies. Yalcinkaya and Singh (2015) have emphasized that the previous BIM review research were typically qualitative and subjective, prone to bias, and included a limited number of reviewed publications. Previous studies indicate that there are various challenges of BIM adoption in FM and provide robust classifications of those challenges factors. However, these studies fail to provide a comprehensive study that based on quantitative analysis approach which help to generalize the outcome of the research results throughout the statistical analysis basis. Also, these challenges of BIM in FM never been tested in Australian context.

This study bridges this gap and adopts a quantitative analysis approach to solve this issue and to provide a better understanding in this regards by directing a comprehensive questionnaire survey that targeting BIM-FM professionals in Australia. In fact, a better understanding of impeding factors of BIM adoption in FM is necessary to devise appropriate strategies for BIM, especially in countries where BIM is fairly new to the FM context.

RESEARCH METHODOLOGY

In this study, a questionnaire was designed to quantify the effects of various impeding factors for BIM in FM. The data collection through a questionnaire survey was carried out between Nov 2017 to Dec 2018 in Australia. Prior to data collection stage, an expert judgment procedure was conducted between Aug and Nov, 2017. The objectives of the expert judgment procedure was to explore whether the questions and the instructions of the questionnaire survey were clear and understandable. Also, to make sure that the questions conveyed consistent meaning for all respondents. After doing all the required corrections, the questionnaire was designed through Opinio and published online in Nov, 2017. Accordingly, the participants were 134 in total during about one year duration. The questionnaire consists of two parts: (1) general information regarding the respondents; and (2) the impeding factors for BIM in FM. The respondents were asked to evaluate the importance of the listed impeding factors using a 1–7 point Likert scale, where (1) represents strongly disagree and (7) represents strongly agree.

THE IMPEDING FACTORS FOR BIM IN FM

An extensive review of impeding factors was performed to generate a list of impeding factors. The impeding factors for BIM in FM used in this research are listed in Table 1A and Table 1B as shown in Appendix A. The initial list contained more than 25 factors, which were then reduced to 17 factors as shown in Table 1A and Table 1B. Nine barriers that have been identified by Becerik-Gerber et al. (2012) were adopted, because they included the most common barriers which have been mentioned in other studies in different ways such as (Kassem et al., 2015, Volk et al., 2014, Yalcinkaya and Singh, 2014, Hsieh et al., 2019, Gao and Pishdad-Bozorgi, 2019, Dixit et al., 2019, Pärn et al., 2017, Miettinen et al., 2018, Kiviniemi and Codinhoto, 2014). The rest of barriers (eight barriers) were adopted from other different studies such as (Kassem et al., 2015, Volk et al., 2014, Yalcinkaya and Singh, 2014, Hsieh et al., 2019, Gao and Pishdad-Bozorgi, 2019, Dixit et al., 2019, Pärn et al., 2017, Miettinen et al., 2018, Kiviniemi and Codinhoto, 2014). However, as mentioned, those barriers have not been examined in quantitative manner, nor in Austrian context which made the research gap for the current study.

A team of two highly experienced BIM consultants and two university professors was establish to give their opinion on the impeding factors list. The final list was adopted as shown in Table 1A, and Table 1B in Appendix A, which included in the questionnaire survey.

DISCUSSION OF THE RESULTS

General characteristics of respondents

Table 2shows general characteristics of the respondents. Although women make up a good proportion of the community, their participation in the survey was 29.9 % only, and 70.1 % for the men. Age of respondents was categorized into four clusters. The first cluster was under 30 years, and that was 35.1%, the second cluster was 30-39 years which made 38.1%, the third cluster was 40-49 years and that made 17.9 %, and the last age cluster was 50 years and over which made 9%.Regarding the level of education of the respondents, the first level was is undergraduate that made(23.9%), and the second level was postgraduate that made (50.0%), others level was certificate or associates degree / licensure that made (26.1%) from respondents were the part of research study. The largest percentage of Job experience was (1-3) years that made 45.5%, while the category (4-6) made 11.2% which was the lowest category. The category (7-9) was 13.4% and the category (10 and over) was 29.9%.Regarding the company using BIM, the largest percentage was (1-3) years that made 50.7%, while the category (4-6) made 20.9% the lowest category.The category (7-9) made 9.7% and finally, the category (10 and over) made 18.7%.

Overall, the participants in this research provided reliable and useful information because the participants were well informed and within the targeted community.

Table 2. The general characteristics of the respondents

Variable	Category	Frequency	Percentage(%)
Gender	Male	94	70.1
	Female	40	29.9
Age of	Under 30	47	35.1
	30-39	51	38.1
	40-49	24	17.9
	50 and over	12	9.0
Education	Undergraduate	32	23.9
	Postgraduate	67	50.0
	Others certificate or associates degree / licensure	35	26.1
Job Experience	1-3	61	45.5
	4-6	15	11.2
	7-9	18	13.4
	10 and over	40	29.9
Company using BIM	1-3	68	50.7
	4-6	28	20.9
	7-9	13	9.7
	10 and over	25	18.7

Descriptive analysis of the collected data

Table 3 provides descriptive statistics of the impeding factors of BIM in FM based on the 91 responses after data screening process and removing the incomplete responses.

The findings suggest that *unknown FM data requirements, Lack of FM team participation in the design phase, timeliness training before hand-over stage, Lack of effective collaboration between project stakeholders for modelling and model utilization, entrenched traditional practices and lack of best practice, and organization wide resistance* are the most significant barrier of BIM adoption in FM, whereas *undefined fee structures for additional scope, unclear roles and responsibilities for loading data into the model or databases and maintaining the model, maturity of BIM standards and frameworks, lack of sufficient legal framework, cultural barriers toward adopting new technology, and Inappropriate technologies and reluctance to use open standards for information exchange* have been considered less significant.

Unknown FM data requirements got the highest mean value with 5.13 as shown in Table 3, and this refers clearly on how large is the gap between all the project phases and the FM phase. In fact, in most design and the construction practice, they are unaware about the project requirements during the operation and management phase of the project. This leads to the ignorance of the most FM details during the development of BIM by the design and construction team. Consequently, it is normal that *the Lack of FM team participation in the design phase* barrier got the second importance rank with 5.08 mean value. This shows the need to engage FM team in the early stage of the design phase, so they can collaborate and provide the FM data and information to the design team in a way the can be compatible with the BIM requirements. This concept called design for FM which leads to decrease the conflict between BIM and FM to the minimum. *Timeliness training before hand-over stage* got 5.02 mean value and placed in the third rank of the importance barriers. This is quite fair as FM team is often highly unaware of what is contained in BIM until the hand-over stage finished. Accordingly, FM team spends huge time and efforts to arrange and provide the necessary information to the FM system and practices. This leads to cost and time overrun. *Lack of effective collaboration between project stakeholders for modelling and model utilization barrier scored* 4.98 mean value in 4th rank. Recent research has revealed the importance of the collaboration among all project stakeholders in order to build up the BIM repository with proper information and data to use them effectively later during the whole project life cycle. *Entrenched traditional practices and lack of best practice* has similar importance value to the previous barrier. People in general face the change in different levels. Change may put some pressure on the stakeholders to practice new approaches which may have some difficulties and uncertainties. *Diversity in BIM and FM software tools, and interoperability issues* is very close to the previous two barriers. Selection of the best fit software tools is a very crucial issues. Research has shown the negative consequences when using different incompatible platforms. *Organization wide resistance: need for investment in infrastructure, training, and new software tools* shows high level of importance as well. This concept has been discussed above. *Necessity yet difficulty in software vendor's involvement* is another barriers which got 4.91 mean value. In fact, missing of software vendor's involvement causes possibilities of misunderstanding the project requirements well, which may lead to improper decisions. *Uncertainties in client-side lifecycle management strategies* another important barrier with 4.90 mean value. Clint priorities may change from time to time depending on many aspect from the client side and causes some barriers to BIM adoption strategies. 4.86 mean value is for *Lack of real-world cases and proof of positive return of investment*. The usual question for any owner and investor is whether the certain tool worth its investment cost or not? At the end, the owner and investors need a real and tangible profit. Another barrier, namely *IT skills shortages* shows acceptable level of importance with 4.83 score.

Table 3. Descriptive Statistics of the impeding factors of BIM in FM

ID	**Impeding factors**	**Mean**	**Std. Deviation**	**Variance**
Q14	Unknown FM data requirements	5.13	1.376	1.892
Q12	Lack of FM team participation in the design phase, which means their ability to influence data requirements and specifications are limited	5.08	1.351	1.825
Q13	Timeliness training before hand-over stage, as FM team is largely unaware of what is contained in as built model until the hand-over stage	5.02	1.299	1.688
Q9	Lack of effective collaboration between project stakeholders for modelling and model utilization	4.98	1.453	2.111
Q11	Entrenched traditional practices and lack of best practice	4.98	1.414	2.000
Q8	Diversity in BIM and FM software tools, and interoperability issues	4.97	1.309	1.715
Q18	Organization wide resistance: need for investment in infrastructure, training, and new software tools	4.97	1.336	1.785
Q10	Necessity yet difficulty in software vendor's involvement, including fragmentation among different vendors, competition, and lack of common interests	4.91	1.435	2.059
Q23	Uncertainties in client-side lifecycle management strategies	4.90	1.422	2.023
Q21	Lack of real-world cases and proof of positive return of investment.	4.86	1.480	2.190
Q16	IT skills shortages	4.83	1.432	2.051
Q19	Undefined fee structures for additional scope	4.79	1.403	1.967
Q7	Unclear roles and responsibilities for loading data into the model or databases and maintaining the model	4.78	1.497	2.240
Q22	Maturity of BIM standards and frameworks	4.74	1.497	2.241
Q20	Lack of sufficient legal framework for integrating owners' view and the actual influence in the design and construction;	4.69	1.427	2.038
Q17	Cultural barriers toward adopting new technology	4.65	1.559	2.431
Q15	Inappropriate technologies and reluctance to use open standards for information exchange	4.59	1.476	2.177

FM current systems and practices suffers from low IT adoption in compare to the first project phase. The common sense is that the FM team is still considered a quite far from the first project phases team concerns and targets. Successes project should have integrity among all the project stakeholders and during all project lifecycle. This is considered the most significant issue for the successful BIM adoption, because BIM is a data repository for the whole project lifetime. The following barriers *Undefined fee structures for additional scope, Unclear roles and responsibilities for loading data into the model or databases and maintaining the model, Maturity of BIM standards and frameworks, Lack of sufficient legal framework for integrating owners' view and the actual influence in the design and construction, Cultural barriers toward adopting new technology, and Inappropriate technologies and reluctance to use open standards for information exchange* are on the bottom of the importance level as shown in Table 3. However, their mean values ranging from 4.79 to 4.59. This means that even the lowest mean value is still importance and above the average of (1-7) Likert Scale which is 3.50. Overall, all the studied barriers are acceptable and show a good level of importance. Overall, it is expected with the outcome of this study that FM professionals and organizations can better understanding the barriers behind the BIM adoption in FM.

CONCLUSIONS

In the last decade, there has been a growing interest in BIM adoption in whole project lifecycle. However, BIM adoption is still risky and challenging, specifically after the project completion and starting the operation and management phase. Issues such as interoperability, lack of experience, and change work tradition, etc. could be the primary reasons. The major aim of this study were to identify impeding factors of BIM adoption in FM and quantify their importance levels which contribute to better understanding of BIM adoption in FM in Austrian context.

Analysis of impeding factors of BIM adoption in FM was done in through basic statistics to find out the most important items among a list of 17 variables. Based on the findings of data analysis of 91 responses, unknown FM data requirements, Lack of FM team participation in the design phase and timeliness training before hand-over stage are the top significant barrier. Also, results showed that undefined fee structures for additional scope, unclear roles and responsibilities and maturity of BIM standards and frameworks have been considered less significant. However, all barriers showed an acceptable level of importance and scored above the mean value of 3.50. This means that all the studied barriers are significant and important and should be considered during the BIM adoption in FM.

The findings of this study can be helpful for guiding senior managers of FM departments and organizations and BIM consultants for a better adoption process. The FM organizations that intend to adopt BIM are advised first to invest in interoperability between FM systems and BIM requirements. They should keep in mind that benefits will be realized in the long term adoption to achieve the return on their investments. The necessary data for the study reported in this paper was collected from professionals and experts in Australia, and therefore reflect their perceptions and experiences. Data collected from a different country might produce different results. Future research may extend this study by performing case studies to have better understanding of the adoption process in FM. Possibly, it will investigate why and how BIM is adopted in different types of FM departments and organizations.

APPENDIX A

Table 1A Technology and Process Barriers

ID	**Barriers Factors**	**Level of agreement from 1=highly disagree to 7 highly agree**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Q7	Unclear roles and responsibilities for loading data into the model or databases and maintaining the model							
Q8	Diversity in BIM and FM software tools, and interoperability issues							
Q9	Lack of effective collaboration between project stakeholders for modelling and model utilization							
Q10	Necessity yet difficulty in software vendor's involvement, including fragmentation among different vendors, competition, and lack of common interests							
Q11	Entrenched traditional practices and lack of best practice							
Q12	Lack of FM team participation in the design phase, which means their ability to influence data requirements and specifications are limited.							
Q13	Timeliness training before hand-over stage, as FM team is largely unaware of what is contained in as built model until the hand-over stage							
Q14	Unknown FM data requirements							
Q15	Inappropriate technologies and reluctance to use open standards for information exchange							
Q16	IT skills shortages							

Table 1B Organizational Barriers

ID	Barriers Factors	Level of agreement from 1=highly disagree to 7 highly agree						
		1	2	3	4	5	6	7
Q17	Cultural barriers toward adopting new technology							
Q18	Organization wide resistance: need for investment in infrastructure, training, and new software tools;							
Q19	Undefined fee structures for additional scope;							
Q20	Lack of sufficient legal framework for integrating owners' view and the actual influence in the design and construction;							
Q21	Lack of real-world cases and proof of positive return of investment.							
Q22	Maturity of BIM standards and frameworks							
Q23	Uncertainties in client-side lifecycle management strategies							

REFERENCES

ARAYICI, Y., ONYENOBI, T. & EGBU, C. 2012. Building information modelling (BIM) for facilities management (FM): The MediaCity case study approach. *International Journal of 3D Information Modelling,* 1**,** 55-73.

BARBAROSOGLU, B. V. & ARDITI, D. 2019. A System for Early Detection of Maintainability Issues Using BIM. *Advances in Informatics and Computing in Civil and Construction Engineering.* Springer.

BECERIK-GERBER, B., JAZIZADEH, F., LI, N. & CALIS, G. 2012. Application Areas and Data Requirements for BIM-Enabled Facilities Management. *Journal of Construction Engineering and Management,* 138**,** 431-442.

BROOKS, T. J. & LUCAS, J. D. 2014. A Study to Support BIM Turnover to Facility Managers for Use after Construction. *Computing in Civil and Building Engineering (2014)***,** 243-250.

DIXIT, M. K., VENKATRAJ, V., OSTADALIMAKHMALBAF, M., PARIAFSAI, F. & LAVY, S. 2019. Integration of facility management and building information modeling (BIM) A review of key issues and challenges. *Facilities*.

GAO, X. & PISHDAD-BOZORGI, P. 2019. BIM-enabled facilities operation and maintenance: A review. *Advanced Engineering Informatics,* 39**,** 227-247.

HSIEH, C.-C., LIU, C.-Y., WU, P.-Y., JENG, A.-P., WANG, R.-G. & CHOU, C.-C. 2019. Building information modeling services reuse for facility management for semiconductor fabrication plants. *Automation in Construction,* 102**,** 270-287.

KASSEM, M., KELLY, G., DAWOOD, N., SERGINSON, M., LOCKLEY, S., KUMARASWAMY, M. & LOVE, P. 2015. BIM in facilities management applications: a case study of a large university complex. *Built Environment Project and Asset Management,* 5.

KIVINIEMI, A. & CODINHOTO, R. 2014. Challenges in the implementation of BIM for FM—Case Manchester Town Hall complex. *Computing in Civil and Building Engineering,* 2014**,** 665-672.

LEE, S.-K., AN, H.-K. & YU, J.-H. An Extension of the Technology Acceptance Model for BIM-based FM. Construction Research Congress 2012@ sConstruction Challenges in a Flat World, 2012. ASCE, 602-611.

MIETTINEN, R., KEROSUO, H., METSÄLÄ, T. & PAAVOLA, S. 2018. Bridging the lifecycle. *Journal of Facilities Management*.

PÄRN, E., EDWARDS, D. & SING, M. 2017. The building information modelling trajectory in facilities management: A review. *Automation in Construction,* 75**,** 45-55.

VOLK, R., STENGEL, J. & SCHULTMANN, F. 2014. Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in construction,* 38**,** 109-127.

YALCINKAYA, M. & SINGH, V. Building information modeling (BIM) for facilities management–literature review and future needs. IFIP International Conference on Product Lifecycle Management, 2014. Springer, 1-10.

YALCINKAYA, M. & SINGH, V. 2015. Patterns and trends in building information modeling (BIM) research: a latent semantic analysis. *Automation in Construction,* 59**,** 68-80.

INTERNET OF THINGS – OPTIMIZING OPPORTUNITIES IN AUSTRALIAN CONSTRUCTION INDUSTRY

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Australia's digital economy is set to contribute $139 billion by 2020. It is predicted that Internet-of-Things (IoT) opportunities in the construction sector is set to add $75-96 billion annually through tangible and intangible cost savings. In such a scenario, it is necessary to evaluate the roadmap of opportunities that IoT provides to the Australian construction sector while providing a conceptual framework for its smooth uptake to maximize the benefit generated. This study follows the potential impacts of digitalization by referring to numerous used cases in this field. It seeks to map out the strategies of the Australian government and its' States regarding its adoption. Finally, key drivers of IoT adoption in the Australian Construction Industry are deduced and highlighted to assist governments, industry personnel, researchers and practitioners to plan out their IoT solutions in an integrated and holistic way for maximizing the value addition.

Keywords: Internet of Things, Digitization, Australian Construction Industry

INTRODUCTION

The Construction industry in Australia with a GDP of around $125 billion as of 2017(Australia's IoT Opportunity: Driving Future Growth An ACS Report 2018) contributes 7% of Australia's overall GDP. It employs 1.1 billion people (10% of the total population) which makes it Australia's second largest employer(ABS 2018). Recent stagnation in the mining construction industry combined with the cessation of the residential housing boom had put a significant hold on growth, but the infusion of a large number of government-funded infrastructure projects has reversed that trend. Furthermore, continued population growth which predicts a doubling of the population to 43 million in 2056 will continue providing an impetus for rapid growth in the construction sector (Parliament of Australia, "Australia's Future Population" 2010).

However, in terms of productivity growth, the Construction industry has been grossly underperforming. A Productivity Commission inquiry reported that the productivity growth has been sluggish, and there has been significant wastage in construction operations (East 2013). Increasing labour shortages due to the continuous rise in the volumes of work and strict deadlines pit Australia's aging workforce into a continuous struggle to meet unrealistic deadlines and subjected to harsher work environments. Also, traditional methods of construction in addition to being physically demanding, also portray a non-glamorous and unattractive image that hinder youngsters from taking up this vocation. Hence, there is an urgent need to integrate automation in the construction industry that would significantly reduce the chaos and unpredictability associated with the construction industry and streamline all activities in a systematic, organisational manner that would make not only make planning and monitoring easier but also provide essential tools to ground level foremen to efficiently perform their task with optimum productivity.

This paper seeks to highlight the unique opportunities that the Internet-of-Things presents towards solving most of the crucial problems facing the Australian construction industry. It is predicted that the IoT will have a fiscal impact of saving 22-29% of the total costs in construction equating to $75-96 billion in annual benefits (Australia's IoT Opportunity: Driving Future Growth An ACS Report 2018). The implications, impacts, and possible hindrances of the application of IoT technologies in the Australian construction sector are discussed, and a conceptual framework is developed that would ensure its smooth uptake to deliver maximum benefit.

Internet of Things

The Internet-of-Things (IoT) is a concept first coined around two decades back by Kevin Ashton in the context of supply chain management (Ashton 2009). It is defined as a network of physical objects with sensing and communication capabilities that enable data synthesis and processing through seamless access to domain-specific software and services (Perera et al. 2014). Ashton notes that its promise lies in enabling physical objects to record, generate, and act upon information on the internet. These tasks were hitherto primarily performed by people, who have shortcomings of limited time, attention and accuracy to be effective at capturing data about the real world for decision-making. Perera (2014) state that IoT is not a revolutionary technological step, but rather the next phase in the evolution of the internet itself, enabled by low-cost and ubiquitous sensors and connectivity.

The IoT is typically composed of three components:

- Hardware - Sensors/RFID tags, data collection devices.
- Middleware - Software/platform for data analytics and processing. Typically it demands ample storage and high computing/processing power to deal with a large amount of data (Big Data)
- Presentation - Data visualization and interpretation tools. It comprises the end-product of IoT and could be in the form of a dashboard or platform that provides the processed data into useful graphical forms/values that add value and benefits to the end-user.

INTERNET OF THINGS FROM THE PERSPECTIVE OF THE CONSTRUCTION INDUSTRY

The Construction Industry has often been seen as laggards when it comes to adapting to emerging technologies. The Internet of Things (IoT) provides exciting opportunities for the Construction Industry to shed this unwanted tag and be on the forefront of utilizing IoT to solve its time and resource constraints and frequent defaults. Construction operations are typically spread across large areas and require remote collaboration between multiple contrasting departments and resources that create the need for ubiquitous, rapid, and automated decision-making on the worksite (Louis &

Dunston 2018). The Internet of Things (IoT) utilizes systems such as sensors and connected devices to monitor real-time parameters and harness the information gleaned through techniques like data analytics and data mining to provide visually informative end-results. For the construction industry to address the modern technological challenges in this Industry 4.0 age, it needs to adapt and transform itself from its traditional primitive methods to digitalized automated systems which will act as a major step forward towards improving its productivity, efficiency, and sustainability and lead to dynamic planning and management (Dallasega 2018).

IoT will ensure high speed of reporting reducing the cost of communication. It will ensure better process control and optimization. The huge amount of data collected would cause monitoring and analysis even at the micro-level that would lead to better accountability and transparency and highlighting of the KPIs and their adequate monitoring. Cutting edge technology like bricklaying robots (FastBrick Robotics), automated OH & S reporting (SmartSite), asset management (AutoDesk Fusion Connect), drone technology for aerial survey and monitoring, embedded technology in building components providing intelligent structural elements(Smart Products) will change the "way of work" of the construction industry.

GROWTH OF INTERNET OF THINGS IN AUSTRALIA

1. Australian National Digital Engineering Policy -

The Australian National Digital Engineering policy states among its goals to provide a framework that promotes a greater uptake of Digital Engineering by the AEC industry nationally to encourage innovation and efficiency in their delivery and management of public infrastructure. It seeks to promote consistency and openness in the data requirements of major public building assets to facilitate an integrated approach to industry in the application of Digital Engineering. It further states that while national consistency is the approach to Digital Engineering and the data requirements for major projects is a prime objective, state and territory jurisdictions shall continue to operate within their own policy parameters.

2. IoT Alliance Australia (IOTAA) –

Internet of Things Alliance Australia (IOTAA) is the peak industry body representing the IoT consortium in Australia. It comprises 450 participating organisations and 850 individual participants who are working towards accelerating the adoption of IoT across Australia. The tagline of this organization is , "Seizing the IoT opportunity for Australia". Its sectoral focus comprises of Smart Cities, Food and Agribusiness, Water, Energy, Transport, Manufacture, and Health. It is responsible for developing and formulating IoT strategies for Australia.

3. New South Wales Digital Government Strategy –

The NSW Digital Government Strategy seeks to harness the potential of digital and emerging technologies to transform the lives of the people at NSW by designing policies and services that are smart, simple and seamless. It sets out four enablers that shall support this vision - technology, cyber security, legislation, and delivery capability. Three digital priorities will be embedded in service design, prioritization and delivery- customer experience, data (forecasting and benchmarking), digital on the inside (using Artificial Intelligence/Machine/ Cognitive Learning/Automation).

4. Digital Western Australia: Western Australian Government Information and Communication Technology (ICT) Strategy (2016-20) –

The strategic goals of this strategy seek to realise a simple and interconnected government delivering effective community services by simplifying technology platforms, systems and standards as part of a unified government; connecting agencies and the community through digital services and system integration; inform decision-makers, frontline staff and the public with quality data and analysis. The key government principles include innovation, collaboration and transformation of existing public services through the use of digital and emerging technologies.

5. Digital Territory Strategy (Northern Territory) –

The Northern Territory Government's Digital Territory Strategy establishes a framework for maximizing the opportunities of the digital age across business, industry, education community and government sectors. Its key directions include using digital technologies to : grow jobs and business, connect territory communities, build digital skills, enable smarter communities, improve government services. In order to deliver on the strategy's five directions, an annual Digital Territory Action Plan shall be published incorporating different phases of Deliver-Design-Explore.

6. South Australian Government ICT Strategy 2018-2021 –

The key objectives for the South Australian Government ICT strategy include: better access for government employees and citizens through identity transformation and centralized network, seamless service delivery through hybrid and multi-cloud IT environments, connected government through Internet Protocol policy framework and interoperability solutions, contemporary IT architecture using cloud computing and Internet-of-Things (IoT).

7. Digital Enablement for Queensland Infrastructure: Principles for BIM implementation (Nov 2018) –

This strategy provides a framework that enables the use of BIM on the full lifecycle of infrastructure projects, delivering measurable benefits. It seeks to increase capacity and capability within the public sector to maximize value from the use of BIM on state infrastructure assets.

8. Tasmanian Government ICT Strategy (Dec 2011) –

The Tasmanian Government seeks to improve productivity in the public sector through investment in ICT. It seeks to improve and transform service delivery to a more client-centric, integrated version.

9. Victorian Digital Assets Strategy –

The State of Victoria in Australia is setting a roadmap towards embracing the Internet of Things (IoT) revolution trending across the globe. According to their Digital Assets

Strategy, they have listed the use of innovative technologies like real-time sensors, Internet-of-Things (IoT), augmented reality, virtual reality, and predictive maintenance as one of their long-term (5+ years) goals. The VDAS (Victorian Digital Assets Strategy) seeks to define and implement the concept of digital engineering to improve the efficiency of processes and facilitate decision-making by real-time simulation of activities before mobilization. In keeping with the Victorian government's strategies, this study will seek to perform an exhaustive review of the application of IoT techniques in the Construction Industry and provide a framework on its application by VDAS.

USED CASES OF IOT APPLICATIONS IN CONSTRUCTION

We look at some implementations of IoT (Internet-of-Things) in the construction industry and their impact and potential risk. The literature includes scientific publications obtained from the Scopus database highlighted in Table 1. We shall use the lessons gained from this review to provide a roadmap for future-proofing the Australian construction industry using the Internet-of-Things. The publications have been categorized into four major domains of Smart Buildings, IoT in Construction, Environmental Sustainability, and Construction Methodologies to illustrate the major trends of research in this sector. Relevant critique and research gap have been included to assist in providing a roadmap for future work as outlined by prior research work.

Table 1 Summary of application of IoT techniques in the construction sector

Domain	Sub -Domain	Year	Title	Authors	Research Gap
Smart Buildings	Adoption of IoT for the development of smart buildings	2019	Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications	Mengda Jiaa, Ali Komeilya, Yueren Wangb, Ravi S. Srinivasana	Deals with post-construction maintenance part of buildings
	Assessing the concept of an intelligent system in the context of a building facade	2019	State-of-the-art of intelligent building envelopes in the context of intelligent technical systems	Jens Böke, Ulrich Knaack and Marco Hemmerling	Conceptual framework restricted to possible transformation of building facades through cyber-physical systems
	Literature review to analyse the research trends in the field of smart houses	2018	Development trends in intelligent homes	Chen I.-C., Sheu J.-S., Huang H.-W.	Scope limited to residential buildings
	Improve Energy Efficiency of Buiding through IoT-Real Life Case Study	2018	Formulating smart integrated workspace concept to improve energy efficiency	Berawi M.A., Miraj P., Naomi F.	Focuses only on improving energy efficiency not user comfort/behaviour

	Assesses IoT Acceptance level in Smart Home Users	2017	Comprehensive Approaches to User Acceptance of Internet of Things in a Smart Home Environment	Park E., Cho Y., Han J., Kwon S.J.	Scope limited to South Korea
	Defines a digitally enabled framework for operating cognitive buildings. Applied on a case study in University of Brescia, Italy	2016	Exploiting internet of things and building information modeling framework for management of cognitive buildings	Pasini D., Mastrolembo Ventura S., Rinaldi S., Bellagente P., Flammini A., Ciribini A.L.C.	Operational stage of a building is focused without integrating the design and construction stages into the framework.
	Analysis of the uncertainty in Internet of Things (IoT) in smart buildings	2015	The Most Important Aspects of Uncertainty in the Internet of Things Field - Context of Smart Buildings	Magruk A.	Deductions inferenced from bibliographic analysis without presenting a real-life case study or industry personnel responses through questionnaire
IoT in Construction	Literature Review of use of IoT in Construction Supply Chain	2018	Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review	Dallasega P., Rauch E., Linder C.	Generalizability of framework to large and small companies. Cultural and social norms not investigated.
	Risks and Impact of IoT on Construction & Production Industry	2018	Employee empowerment in the context of domain-specific risks in industry 4.0	Digmayer C., Jakobs E.-M.	Limited to CAx systems - lack of generalizability of specified tool.
	Longitudinal literature review that argues that IoT concept must be transformed from “point solutions” to an integrated ecosystem changer of the construction industry	2018	Digital construction: From point solutions to IoT ecosystem	Woodhead R., Stephenson P., Morrey D.	Specified to socio-political conditions in the United Kingdom
	Practical implications of adoption of IoT in Construction Industry	2016	Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry	Oesterreich T.D., Teuteberg F.	Analysis is done based on bibliometric analysis. Socio-economic and human perception factors to be analysed by relevant questionnaire surveys

	Detailed literature review investigating the application of Big Data techniques in the Construction Industry	2016	Big Data in the construction industry: A review of present status, opportunities, and future trend	Bilal M., Oyedele L.O., Qadir J., Munir K., Ajayi S.O., Akinade O.O., Owolabi H.A., Alaka H.A., Pasha M.	Socio-economic and human perception factors not analysed
	Political, economic, social, technological, environmental and legal implications of adoption of IoT in Construction Industry	2016	Opportunities and risks of digitalization in the construction industry in the context of Industry 4.0 - Situation analysis and definition of goals in the course of a technical impact assessment	Oesterreich T.D., Teuteberg F.	Human perception regarding the various techniques analysed among industry personnel to be researched through relevant questionnaire surveys
Environmental sustainability	Reduce Carbon Emission during construction activities	2018	Greenhouse gas emission monitoring system for manufacturing prefabricated components	Tao X., Mao C., Xie F., Liu G., Xu P.	Limited to pre-fabricated components
	Use of IoT in Prefabricated Construction	2018	Real-Time Carbon Emissions Monitoring Tool for Prefabricated Construction: An IoT-Based System Framework	Mao C., Tao X., Yang H., Chen R., Liu G.	Localized to pre-fabricated components.
	Framework for building management cloud platform for green buildings	2017	Design an IoT-based building management cloud platform for green buildings	Wang M., Qiu S., Dong H., Wang Y.	Conceptual framework yet to be tested in real-life scenario
	Analyze the green building simulation based on smart-sensing and IoT	2017	Research on the green building simulation based on smart-sensing and IoT	Lai X.	Conceptual framework yet to be tested in real-life scenario
Construction Methodologies	Scenarios for promoting automation in construction	2018	Cyber-physical systems for construction industry	Correa F.R.	Conceptual framework yet to be tested in real-life scenario
	Scaffolding Operation using IoT	2018	Scaffolding modeling for real-time monitoring using a strain sensing approach	Cho C., Sakhakarmi S., Kim K., Park J.	Point solution of improving efficiency of scaffolding operations only.
	Improving Construction Supply Chain Management with IoT - Case Studies	2018	Industry 4.0 fostering construction supply chain management: Lessons learned from engineer-to-order suppliers	Dallasega P.	Feasibility of concepts analysed from case studies to be studied further along with necessary incentives and support from public policy for long-term

				technological road-mapping
Bridging the gap between visual management lean construction, reviewing emerging technologies to support conventional VM system and tools	2017	From conventional to IT based visual management: A conceptual discussion for lean construction	Tezel A., Aziz Z.	Scope limited to visual management and lean construction concepts.
Using situational-aware computing for resolving problems in construction management	2017	IoT based situational awareness framework for real-time project management	Ghimire S., Luis-Ferreira F., Nodehi T., Jardim-Goncalves R.	Conceptual framework yet to be tested in a real-life scenario
Providing a method for facilitating the GIS-based fusion of BIM and IoT	2015	BIM and IoT: A synopsis from GIS perspective	Isikdag U.	BIM and IoT fusion taken only from a GIS perspective
Development of an anti-collision automated system for promoting safety in tower crane usage	2014	A practical application combining wireless sensor networks and internet of things: Safety management system for tower crane groups	Zhong D., Lv H., Han J., Wei Q.	Point solution and equipment specific: tower-crane
Development of a software platform for integrating all precast components to improve the supply chain of construction	2014	Study of digital lean construction platform for precast components	Yungui L., Kuining Q., Yongbin W., Tao Z.	Limited to pre-fabricated components
Fusion of RFID and Prefabrication to improve construction productivity	2014	Based on RFID prefabricated building component design and monitoring system research	Wang J.	Limited to RFID and prefabrication "point solutions"
Optimizing design and construction of composite steel bridges through digitalization	2018	Parametric, adaptive design and analysis of standardized steel composite bridges	Giebat, S.	Point solution restricted to composite steel structures. Post construction maintenance of bridges not explored
Digital tunneling operation leading to autonomous tunneling operation in the future	2018	Tunneling 4.0 – Construction-related future trends: Tunnelbau 4.0 – Baubetriebliche Zukunftstrends	Goger G., Bisenberger T.	Conceptual framework to be verified by real-life case study

RESEARCH GAP

It was observed from the preliminary literature review that most of the solutions were point solutions that aimed to satisfy short-term localized goals instead of developing an integrative system for providing “umbrella solutions” targeting any significant aspect of the construction industry as a whole. Although many review papers tried to highlight the possible future impact of growing digitization and IoT in the construction sector, a bibliographic approach without relevant human/industry perception through questionnaires was observed. Various techniques like big data management, data mining, cyber-physical systems, and proposed conceptual frameworks were discussed without sufficient successful examples from real-life case-study implementation. There is an urgent need to translate the theory of IoT into practice in the construction industry with an integrated ecosystem-changing view identifying possible hindrances and formulating measures to mitigate them chalked out in advance.

INTERNET OF THINGS IN THE CONSTRUCTION SECTOR - A ROADMAP FOR FUTURE APPLICATIONS IN AUSTRALIA

The major effects of IoT from the perspective of construction management are:

High-Speed Reporting –
Real-time available data and interconnected devices will significantly improve the speed of reporting and substantially reduce the cost of communication. This will facilitate rapid decision-making and improved implementation of management decisions.

Complete Process Control –
With real-time monitoring of essential parameters, the construction processes will be better controlled and less prone to be negatively affected by external factors. Project managers will exercise greater process control over all the activities, and the unpredictability and disorganization associated with the construction industry would be ameliorated.

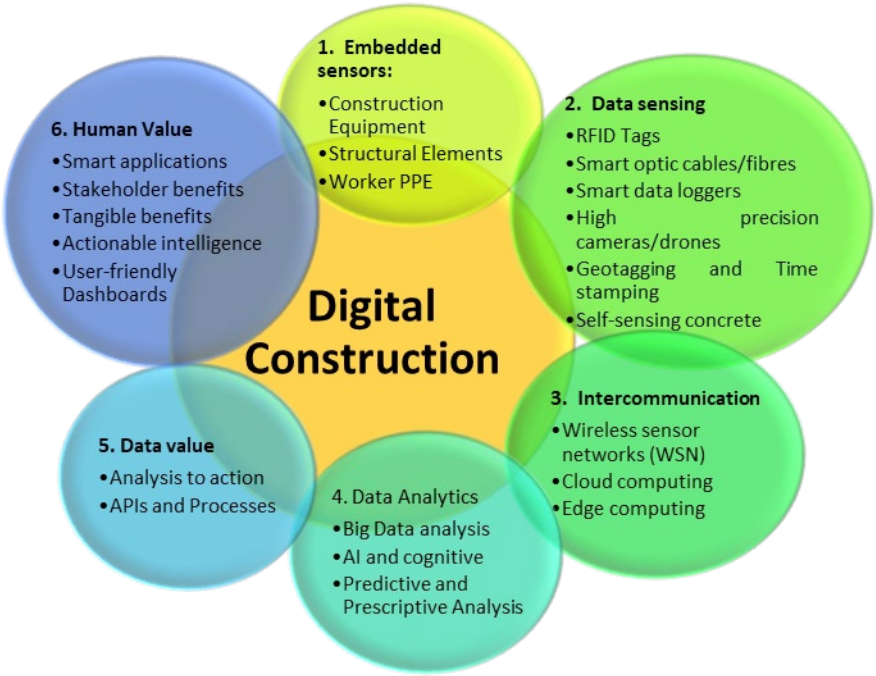

Figure 1 Conceptual Framework for the adoption of IoT in the Australian Construction Industry

Explosion of valuable data –

IoT will bring about the explosion of data due to the numerous ubiquitous devices employed to measure and monitor various parameters for numerous disparate activities. It leads to critical future challenges like data storage and data security. Even cloud-based solutions would prove to be inadequate to contain the enormous influx of data coming from IoT devices (Tang et al. 2019). There needs to be integrated research towards the establishment of data hubs to synchronize and reconcile conflicting data changes, enforce semantic consistency of information and generate unique persistent identifiers by the registry-style data hub which will allow the consuming application to either retrieve or assemble an integrated view.

Deep Data Analytics –

The use of IoT in the Construction Industry will lead to accumulation of intensive data about every aspect and activity involved in the project. This will facilitate the employment of big data analytics techniques like statistics (Carrillo, Harding & Choudhary 2011; Huang & Beck 2013), data mining (Wang & Leite 2013; Wu et al. 2014), machine learning (Chen & Hsu 2007), regression (Siu et al. 2013; Soltanzadeh et al. 2016;), classification (Liu & Jiao 2011; Mahfouz & Kandil 2010), and clustering (Al Qady & Kandil 2014; Fan & Li 2013) to improve the efficiency of construction processes.

Strict ethical and legal implications –

Increasing volume of data and increased demand for their mobility, collaboration and data sharing with external partners and employment of third-party service companies raise important questions regarding data security, ethical and privacy violations and unauthorized access and misuse of privileged data. Companies have to develop strict data usage and IT rules, and policy frameworks to protect the rights of all stakeholders, involved-from workers to clients. Presently, the regulations regarding data access and security are rather vague or in some cases, non-existent when it comes to the construction industry (Oesterreich & Teuteberg 2016).

Higher Expectations –

The use of IoT devices in the construction sector could lead to increasing the expectations of clientele and unrealistic targets set forth as a result. It must be understood that the use of IoT could act as a monitoring tool, not as a magic stick that can solve external problems like harsh site conditions or socio-political issues when it comes to construction projects. The construction industry has to be wary of putting forward over-ambitious expectations when implementing the use of IoT techniques.

Sensors making up a network of interconnected things which have been widely employed in the construction industry are enumerated as follows:

- Vision-Based: The use of cameras for automating a variety of project management tasks (Brilakis & Soibelman 2005) and for monitoring the progress of the project in real-time (Golparvar-Fard, Pena-Mora & Savarese 2012; Zhang et al. 2009).
- Ranging-based: The use of ranging based detection techniques like LiDAR (Light Detection and Ranging) and LADAR (Laser Distance and Ranging) for detecting structural faults and progress status (Tang, Huber & Akinci 2010; Turkan et al. 2012).
- Location Based: Utilizing localization systems like Global Positioning System (GPS) (Lee, Park & Seo 2018) and Ultrawide Band (UWB) for tracking construction activities (Shahi, West & Haas 2013; Teizer, Lao & Sofer 2007).
- Radio Frequency Based (RFID): RFIDs have widespread applications in the Construction Sector, which have been enumerated as follows:
    1. Logistic & Supply Chain Management (Automated Construction Equipment leasing/plant hire)
    2. Inventory Management (Inventory Control & Stock Distribution)
    3. Quality Management (Embedded RFID in building elements to monitor their quality/performance parameters)
    4. Waste Management (Construction & Demolition Waste through Trip Ticket System)
    5. Workforce Management (RFID ID Cards monitoring attendance records and site access)
    6. Worker Safety (RFID chips monitoring essential health diagnostics-heart rate, pulse rate and proximity to danger zones)
    7. Asset Management (tracking of machinery and tools as well as operation stats and predictive maintenance for all equipment)

DISCUSSIONS AND KEY OBSERVATIONS

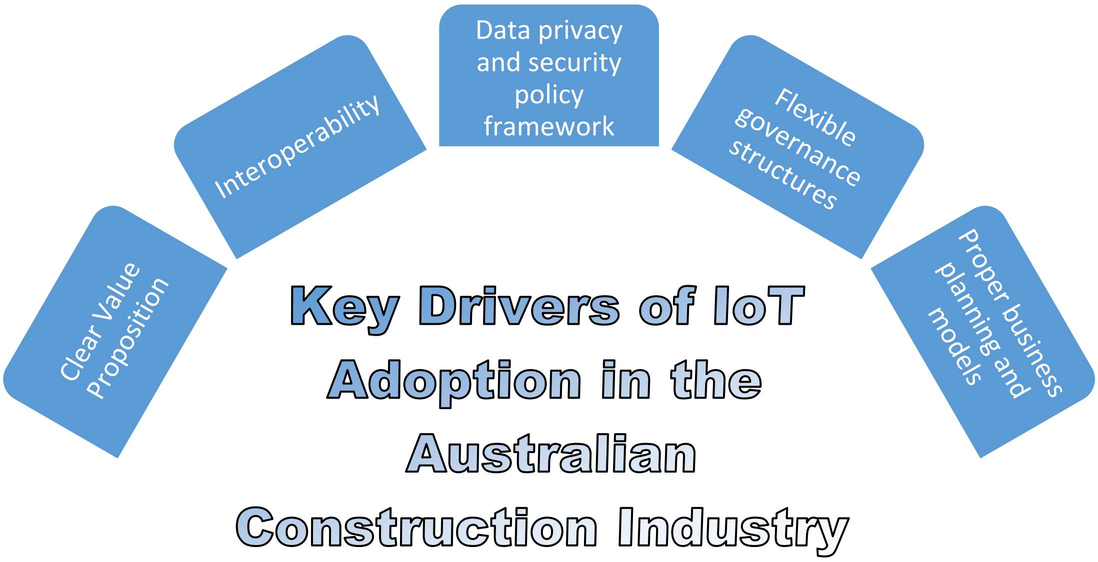

Figure 2 Key Drivers of IoT adoption in the Australian Construction Industry

Some of the possible barriers identified and measures to mitigate them regarding IoT adoption in the Australian construction industry are:

- Lack of interoperability and unclear value propositions: A significant lack of clarity exists between the seamless coordination between various departments regarding the collection, monitoring and regulation of data along with their processing and analysis at an integrated level to enhance decision-making and definite value addition. This obscurity can only be resolved through proper integrated planning before employing IoT devices/techniques on the field. Clear guidelines, policies, and benchmarking regarding the use of IoT devices and procedures would greatly assist in clearing the murky waters.

- Privacy and security concerns: Numerous researchers have expressed concerns over the legality, privacy, and governance of the enormous data generated which if misused could prove to be immensely counterproductive to the main aims of employing IoT. Unscrupulous hackers and data thieves may maliciously corrupt stored data or use historically compiled data to further their nefarious purposes. The security protocols and access have to be carefully developed and monitored to prevent this occurrence.

- Traditional governance structures: Construction industry has traditionally been governed by rigid and bureaucratic hierarchies which are resistant to change and evolution. This provides a significant hindrance to the gradual and smooth uptake of IoT techniques and processes. The only solution is to make the upper management aware of the numerous benefits of IoT especially in a financial context so that change is effected from a top-down flow making it more effective and integrated, rather than a bottom-up approach which results typically in point-solutions as observed from the literature review.

- Business planning and models: Effective business plans are to be formulated incorporating the IoT techniques. A practical benefit-cost analysis proves necessary evidence before the uptake of any new technique in a project. Failure to plan the absorption in a systematic process would provide to be a significant hindrance for the successful adoption of IoT in construction projects.

LIMITATIONS AND FUTURE SCOPE

This study is limited towards optimizing the opportunities presented by the Internet of Things in the Australian context only. Globalizing the research by outlining various national policies and digital strategies of countries around the world would prove to be a valuable outcome that would provide a roadmap to policy-makers, researchers and construction industry personnel to harness the full potential of the Internet of Things towards maximizing the productivity and effectivity of the Construction industry globally. A relevant PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) analysis would provide an in-depth analysis of the various implications of incorporating IoT in the construction sector. It is also necessary to study the market readiness of the construction industry through several maturity studies to gauge the fertility of the seedbed for allowing IoT strategies to blossom in a global context. There is a need to develop an integrative approach towards incorporating IoT strategies instead of limiting to point solutions as has been the scenario in past research.

CONCLUSIONS

The Australian construction industry has seldom been identified as being at the forefront of applying new and cutting-edge technology. It has suffered dramatically in the past due to delayed uptake of several game-changing technologies. If the construction sector is to keep up with the rapid pace of digitalization and survive obsolence in terms of technological progress, there is an urgent need to incorporate the principles and techniques of internet-of-things in its current practices to improve its declining productivity, especially in the Australian context. From extensive literature review in Table 1, the current trends of research in the field of IoT in Construction Industry have been identified with a critical review of possible research gaps and limitations which have been delineated in the table. Credible work has been done by the Australian national and various state governments regarding drafting Digital Assets strategy roadmaps as outlined in the growth of IoT in Australia section, but there remains a growing need to translate theory into practice. A roadmap for illustrating the implications of incorporating IoT strategies in the Australian construction industry has been chalked out, and some of the possible barriers preventing its smooth uptake have subsequently been identified and illustrated in Fig. 2 and discussed adequately. The various limitations and future scope of this study are also discussed briefly to provide a proper context and pathway to researchers for exploring this field of study further.

REFERENCES

ABS 2018, '6291.0.55.003 Labour Force, Australia, Detailed, Quarterly, Table 04. Employed persons by Industry division of main job (ANZSIC) – Trend, Seasonally adjusted, and Original'.

Akyildiz, IF, Su, W, Sankarasubramaniam, Y & Cayirci, E 2002, 'Wireless sensor networks: a survey', Computer networks, vol. 38, no. 4, pp. 393-422.

Al Qady, M & Kandil, A 2014, 'Automatic clustering of construction project documents based on textual similarity', Automation in construction, vol. 42, pp. 36-49.

Arditi, D, Oksay, FE & Tokdemir, OB 1998, 'Predicting the outcome of construction litigation using neural networks', Computer-Aided Civil Infrastructure Engineering, vol. 13, no. 2, pp. 75-81.

Arditi, D & Pulket, T 2005, 'Predicting the outcome of construction litigation using boosted decision trees', Journal of Computing in Civil Engineering, vol. 19, no. 4, pp. 387-93.

Ashton, K 2009, 'That ‘internet of things’ thing', RFID journal, vol. 22, no. 7, pp. 97-114.

Australia’s IoT Opportunity: Driving Future Growth An ACS Report, 2018, ACS.

Brilakis, I & Soibelman, L 2005, 'Content-based search engines for construction image databases', Automation in construction, vol. 14, no. 4, pp. 537-50.

Carrillo, P, Harding, J & Choudhary, A 2011, 'Knowledge discovery from post-project reviews', Construction Management and Economics, vol. 29, no. 7, pp. 713-23.

Chen, J-H & Hsu, S 2007, 'Hybrid ANN-CBR model for disputed change orders in construction projects', Automation in Construction, vol. 17, no. 1, pp. 56-64.

Čolaković, A & Hadžialić, M 2018, 'Internet of Things (IoT): A review of enabling technologies, challenges, and open research issues', Computer Networks.

Dallasega, P 2018, 'Industry 4.0 Fostering Construction Supply Chain Management: Lessons Learned From Engineer-to-Order Suppliers', IEEE Engineering Management Review, vol. 46, no. 3, pp. 49-55.

East, CS 2013, 'This publication is available from the Productivity Commission website at www. pc. gov. au'

Fan, H & Li, H 2013, 'Retrieving similar cases for alternative dispute resolution in construction accidents using text mining techniques', Automation in construction, vol. 34, pp. 85-91.

Ghosh, A & Das, SK 2008, 'Coverage and connectivity issues in wireless sensor networks: A survey', Pervasive Mobile Computing, vol. 4, no. 3, pp. 303-34.

Golparvar-Fard, M, Pena-Mora, F & Savarese, S 2012, 'Automated progress monitoring using unordered daily construction photographs and IFC-based building information models', Journal of Computing in Civil Engineering, vol. 29, no. 1, p. 04014025.

Gong, J, Caldas, CH & Gordon, C 2011, 'Learning and classifying actions of construction workers and equipment using Bag-of-Video-Feature-Words and Bayesian network models', Advanced Engineering Informatics, vol. 25, no. 4, pp. 771-82.

Gubbi, J, Buyya, R, Marusic, S & Palaniswami, M 2013, 'Internet of Things (IoT): A vision, architectural elements, and future directions', Future generation computer systems, vol. 29, no. 7, pp. 1645-60.

Huang, Y & Beck, JL 2013, 'Novel sparse Bayesian learning for structural health monitoring using incomplete modal data', in Computing in Civil Engineering (2013), pp. 121-8.

Jebelli, H, Khalili, MM & Lee, S 2019, 'Mobile EEG-Based Workers’ Stress Recognition by Applying Deep Neural Network', in Advances in Informatics and Computing in Civil and Construction Engineering, Springer, pp. 173-80.

Kim, H, Soibelman, L & Grobler, F 2008, 'Factor selection for delay analysis using knowledge discovery in databases', Automation in Construction, vol. 17, no. 5, pp. 550-60.

Kulkarni, RV, Forster, A & Venayagamoorthy, GK 2011, 'Computational intelligence in wireless sensor networks: A survey', IEEE communications surveys tutorials, vol. 13, no. 1, pp. 68-96.

Lee, SS, Park, S-i & Seo, J 2018, 'Utilization analysis methodology for fleet telematics of heavy earthwork equipment', Automation in construction, vol. 92, pp. 59-67.

Liao, C-W & Perng, Y-H 2008, 'Data mining for occupational injuries in the Taiwan construction industry', Safety science, vol. 46, no. 7, pp. 1091-102.

Lin, H-T, Chi, N-W & Hsieh, S-H 2012, 'A concept-based information retrieval approach for engineering domain-specific technical documents', Advanced Engineering Informatics, vol. 26, no. 2, pp. 349-60.

Liu, H-B & Jiao, Y-B 2011, 'Application of genetic algorithm-support vector machine (GA-SVM) for damage identification of bridge', International Journal of Computational Intelligence Applications, vol. 10, no. 04, pp. 383-97.

Louis, J & Dunston, PS 2018, 'Integrating IoT into operational workflows for real-time and automated decision-making in repetitive construction operations', Automation in Construction, vol. 94, pp. 317-27.

Mahfouz, T & Kandil, A 2010, 'Construction legal decision support using support vector machine (SVM)', in Construction Research Congress 2010: Innovation for Reshaping Construction Practice, pp. 879-88.

Mahfouz, TS 2009, 'Construction legal support for differing site conditions (DSC) through statistical modeling and machine learning (ML)', Doctor of Philosophy thesis, Iowa State University.

Oesterreich, TD & Teuteberg, F 2016, 'Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry', Computers in Industry, vol. 83, pp. 121-39.

2010, Parliament of Australia, “Australia’s Future Population".

Perera, C, Zaslavsky, A, Christen, P & Georgakopoulos, D 2014, Context aware computing for the internet of things: A survey, 1, 1553-877X.

Rujirayanyong, T & Shi, JJ 2006, 'A project-oriented data warehouse for construction', Automation in Construction, vol. 15, no. 6, pp. 800-7.

Sang, Y, Shen, H, Inoguchi, Y, Tan, Y & Xiong, N 2006, 'Secure data aggregation in wireless sensor networks: A survey', in Parallel and Distributed Computing, Applications and Technologies, 2006. PDCAT'06. Seventh International Conference on, pp. 315-20.

Shahi, A, West, JS & Haas, CT 2013, 'Onsite 3D marking for construction activity tracking', Automation in construction, vol. 30, pp. 136-43.

Siu, M, Ekyalimpa, R, Lu, M & Abourizk, S 2013, 'Applying regression analysis to predict and classify construction cycle time', in Computing in Civil Engineering (2013), pp. 669-76.

Soltanzadeh, A, Mohammadfam, I, Moghimbeigi, A & Ghiasvand, R 2016, 'Key factors contributing to accident severity rate in construction industry in Iran: a regression modelling approach', Archives of Industrial Hygiene Toxicology, vol. 67, no. 1, pp. 47-53.

Tang, P, Huber, D & Akinci, B 2010, 'Characterization of laser scanners and algorithms for detecting flatness defects on concrete surfaces', Journal of Computing in Civil Engineering, vol. 25, no. 1, pp. 31-42.

Tang, S, Shelden, DR, Eastman, CM, Pishdad-Bozorgi, P & Gao, X 2019, 'A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends', Automation in Construction, vol. 101, pp. 127-39.

Teizer, J, Lao, D & Sofer, M 2007, 'Rapid automated monitoring of construction site activities using ultra-wideband', in Proceedings of the 24th International Symposium on Automation and Robotics in Construction, Kochi, Kerala, India, pp. 19-21.

Trost, SM & Oberlender, GD 2003, 'Predicting accuracy of early cost estimates using factor analysis and multivariate regression', Journal of construction engineering and management, vol. 129, no. 2, pp. 198-204.

Turkan, Y, Bosche, F, Haas, CT & Haas, R 2012, 'Automated progress tracking using 4D schedule and 3D sensing technologies', Automation in construction, vol. 22, pp. 414-21.

Wang, L & Leite, F 2013, 'Knowledge discovery of spatial conflict resolution philosophies in BIM-enabled MEP design coordination using data mining techniques: a proof-of-concept', in Computing in Civil Engineering (2013), pp. 419-26.

Welbourne, E, Battle, L, Cole, G, Gould, K, Rector, K, Raymer, S, Balazinska, M & Borriello, G 2009, 'Building the internet of things using RFID: the RFID ecosystem experience', IEEE Internet computing, vol. 13, no. 3.

Wu, X, Zhu, X, Wu, G-Q & Ding, W 2014, 'Data mining with big data', IEEE transactions on knowledge and data engineering, vol. 26, no. 1, pp. 97-107.

Zhang, J & El-Gohary, N 2012, 'Automated regulatory information extraction from building codes: Leveraging syntactic and semantic information', in Construction Research Congress 2012: Construction Challenges in a Flat World, pp. 622-32.

Zhang, J & El-Gohary, NM 2013, 'Semantic NLP-based information extraction from construction regulatory documents for automated compliance checking', Journal of Computing in Civil Engineering, vol. 30, no. 2, p. 04015014.

Zhang, X, Bakis, N, Lukins, TC, Ibrahim, YM, Wu, S, Kagioglou, M, Aouad, G, Kaka, AP & Trucco, E 2009, 'Automating progress measurement of construction projects', Automation in construction, vol. 18, no. 3, pp. 294-301.

LINKING CIRCULAR ECONOMY AND MODULARISATION IN ENERGY INFRASTRUCTURE: STATE OF THE ART AND A WAY FORWARD

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Developing sustainable infrastructure leveraging the principles of circular economy is essential for the energy sector to give its maximum contribution towards a low carbon world. Traditional energy infrastructure have a lifecycle predetermined by the lifetime of certain components. This means that the residual lifetime of the other components with a longer life is "wasted". Modular infrastructure might be reconfigurable and extend/adapt their lifecycle decoupling the life of the infrastructure from their modules. In a wider perspective, circular economy would be a cornerstone of this novel strategy to enable the lifecycle of sustainable modular infrastructure. Remarkably, despite the growing interest among policymakers, academics and industry in both circular economy and modularisation, there is a lack of research about the link between circular economy and modularisation in the energy sector. State of the art includes few publications highlighting this link in the building construction sector, and several publications pointing out the link between a modular product and circular economy. Building on this literature, this paper presents a Systematic Literature Review highlighting the state-of-the-art and the gap in knowledge.

Keywords: Modularisation, Circular Economy, Sustainability, Module, Prefabrication, Infrastructure, Energy

INTRODUCTION

"Modular construction" is often called indifferently "modularisation" or "modularity" both in the scientific and industrial literature. However, GIF/EMWG (2007) defines modularisation as the "process of converting the design and construction of a monolithic or stick-built plant to facilitate factory fabrication of modules for shipment and installation in the field as complete assemblies" (Page 24). Furthermore EY (2016) defines modularisation as a "way of simplifying construction by splitting the plant up into packages (modules) which can be factory manufactured, transported to site and assembled in situ, (or close by in an assembly area before being installed)" (Page 20). On the other hand, GIF/EMWG (2005) defines modularity as a "Generic term, representing a comparative use of many standardized smaller units, with a lesser number of larger units, for the same installed capacity (MWe)" (Page 22). Figure 1 further clarifies the definition of modularisation and modularity, also highlighting the meaning of stick-built and pure standardisation.

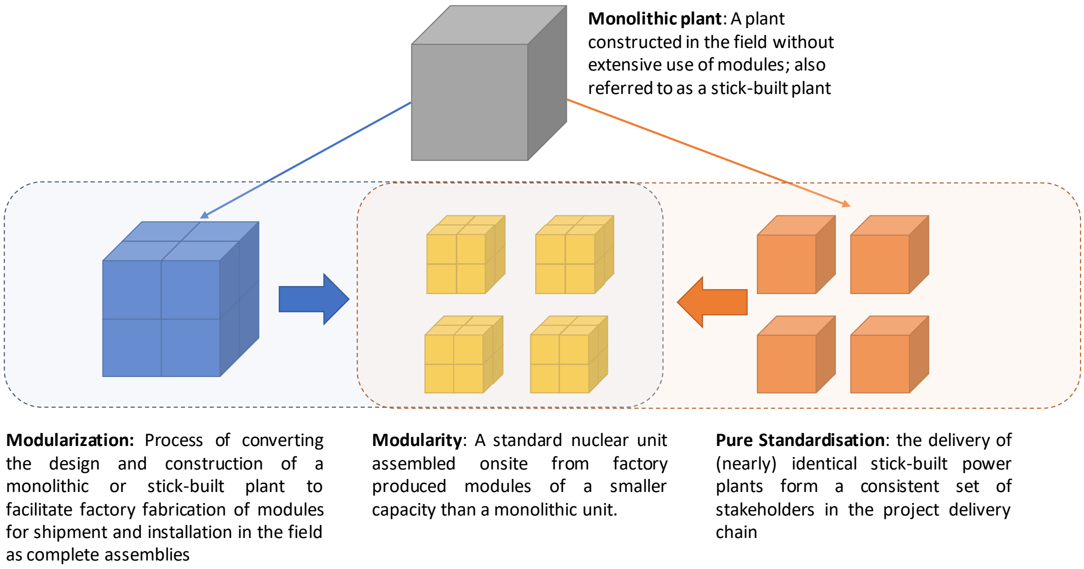

Figure 1: Meaning of modularisation, modularity, standardisation, stick-built. Text adapted from GIF/EMWG (2007)

The meaning of modularisation in this paper is based on the definitions of GIF/EMWG (2007) and EY (2016). Therefore, when the concept of modularisation in several publications is defined as modularity, this paper reports the term "modularisation".

Several authors deal with the costs and benefit of modularisation Azhar et al. (2012); Bondi et al. (2016); De La Torre (1994); Upadhyay and Jain (2016). Factory fabrication is usually cheaper than site fabrication, but the costs associated with shipping of modules to the site must also be considered EY (2016). Smaller sized plants can take better advantage of modularisation since it is possible to have a greater percentage of factory-made components Carelli et al. (2010). Although there are a number of publications in the literature describing the qualitative advantages of modularisation, only a few of them are quantitative. Mignacca et al. (2018) summarise the quantitative information about two key implications of modularisation in infrastructure: schedule reduction (an average of 37.7%) and cost saving (an average of 15%).

Traditional stick-built energy infrastructure have a lifecycle predetermined by certain components. Modular infrastructure could be more reconfigurable and extend/adapt their lifecycle by decoupling the life of the infrastructure from their modules. When a module reaches its end of life, it could be exchanged extending the life of the infrastructure. Furthermore, when the infrastructure reaches the end of life, modules that are still functioning could be used in other infrastructure. In this way, the residual lifetime of certain modules with a longer life is not "wasted". In a wider perspective, circular economy would be a cornerstone of this novel strategy to manage sustainable modular infrastructure.

Vanner et al. (2014) define Circular Economy (CE) as "a development strategy that enables economic growth while aiming to optimise the chain of consumption of biological and technical materials". Furthermore, Preston and Lehne (2017) define the meaning of CE pointing out the goal of maintaining resources at the highest value possible: “The basic idea of the CE is to shift from a system in which resources are extracted, turned into products and finally discarded towards one in which resources are maintained at their highest value possible”. This means:

1. Reusing and repairing products;
2. Recovering components and using them into new products or for new uses;
3. Restructuring a system so that the waste of one process can be the feedstock for another one.

In a CE model, the design not only focuses on functionality but also tries to manage the infrastructure end of life optimally, how the components can become parts of a new infrastructure/production chains Molina-Moreno et al. (2017). Modularisation is applied in the building construction sector contributing to circularity in the following ways European Environment Agency (2017):

1. Waste is in a smaller quantity in a controlled environment (factory) than on a traditional construction site;
2. Less transport of material and stuff, thus determining few emissions;
3. Possibility of disassembling, relocating and refurbishing modules to reuse them, reducing the demand for raw material and the amount of energy;
4. Possibility of repairing/modifying parts or materials without destroying the building’s basic structure.

Furthermore, modularisation could reduce the construction and demolition waste, and could improve the deconstruction process facilitating the achievement of the closed-loop material cycle Cheng et al. (2015); Lehmann (2011a); Pulaski et al. (2004).

In general, when an infrastructure reaches the end of life, it needs to be decommissioned. Decommissioning projects are the new, emerging, global, unavoidable challenges that project managers and policymakers will face more and more severely in the future. Among decommissioning projects, nuclear-decommissioning megaprojects are probably the most studied ones. According to IAEA (2019), there are 453 operational reactors in the world, 170 reactors in permanent shutdown, 55 in construction and only 17 had been completely decommissioned, which means that there will be the need to dismantle at least other 661 nuclear reactors. However, nuclear plants are not the only energy infrastructure to generate decommissioning projects. According to GWEC (2019), the total global wind power installed is 540 GWe, the vast majority installed in the last 10 years. Considering an operating life of about 25 years Ghenai (2012), in a decade or two, there will be decommissioning megaprojects in the wind farm sector. Similar consideration can be given considering about 500 GWe of solar power installed†. These numbers clarify the importance and the impact of extending the lifetime of the infrastructure and their modules.

† This is an approximated number provided by http://www.solareb2b.it/wp-content/uploads/2016/06/SPE_GMO2016_full_version.pdf.

This paper aims, through a Systematic Literature Review (SLR), to identify "what we know" about the link between circular economy and modular energy infrastructure. An SLR, instead of a traditional narrative review, has been conducted to allow repeatability, objectivity and transparency. Figure 2 summarises the research area and the research objective.

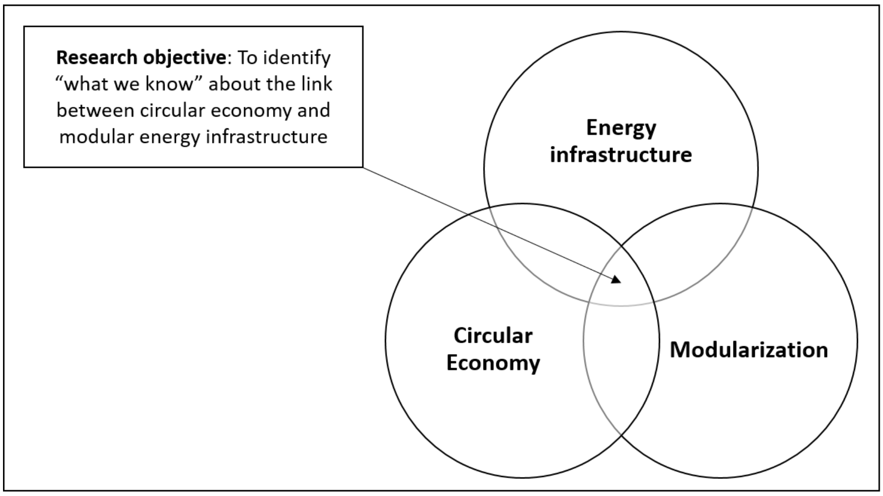

Figure 2: Research area and objective

The rest of the paper is structured as follows: section 2 presents the SLR that highlighted the gap in knowledge; section 3 reports the key lessons learned from other sectors, primarily building and products; section 4 concludes the paper suggesting a way forward.

METHODOLOGY

This methodology section deals with the SLR. Remarkably, if the three elements (circular economy, modularisation, energy infrastructure) are searched together, there are not meaningful publications found (even changing the keywords). Therefore, the authors decided to expand the search by dropping the keywords related to energy infrastructure and analyse all the papers emerged by looking at circular economy and modularisation.

This paper combines the methodologies to conduct an SLR presented by Di Maddaloni and Davis (2017); Sainati et al. (2017). The selection process of the publications includes two sections. Section A deals with publications extracted from Scopus, and section B deals with reports published by key institutions.

Section A has three main stages. The first stage is the identification of relevant keywords related to the research objective. Several iterations led to this list:

- Circular economy: "circular economy", "re-use", "reuse", "repair", "recover", "restructure", "replace".

- Modularization: “modularization”, “modularisation”, “modularity”, “prefabrication”, “pre-fabrication”.

In the second stage, a single string with the Boolean operator *AND*/*OR* is introduced in Scopus:

"circular economy" OR "re-use" OR "reuse" OR "repair" OR "recover" OR "restructure" OR "replace" AND "modularization" OR "modularisation" OR "modularity" OR "prefabrication" OR "pre-fabrication" (search date: 04/02/2019).

Scopus was chosen because of the scientific merit of the indexed literature. A timeframe was not selected a priori but emerged to be 1968-2019 because the first publication is dated 1968. The first selection step used the aforementioned string (applied to title, abstract or keywords) and retrieved 917 publications (excluding 2 non-English publications and focusing on Article, Conference Paper, Review, Article in press, and Book Chapter).

Afterwards, the following subject areas were excluded because not related to the research objective: Computer Science, Mathematics, Physics and Astronomy, Medicine, “Biochemistry, Genetics and Molecular Biology”, Neuroscience, Psychology, Arts and Humanities, Chemistry, Health Professions, Dentistry, Immunology and Microbiology, Nursing, Multidisciplinary, Chemical Engineering. The publications retrieved after the second stage were 366.

The third stage is the “filtering”, which is characterised by a careful reading of the title and abstract of each publication filtering out publications not related to the research objective or duplication. After the filtering stage, 366 publications were removed, leaving zero publications strictly focused on the research objective. However, 7 publications highlight the link between modular building and circular economy, and 12 publications highlight the link between circular economy and modular product. These publications have been carefully read and analysed. Figure 2 summarises the Section A of the selection process.

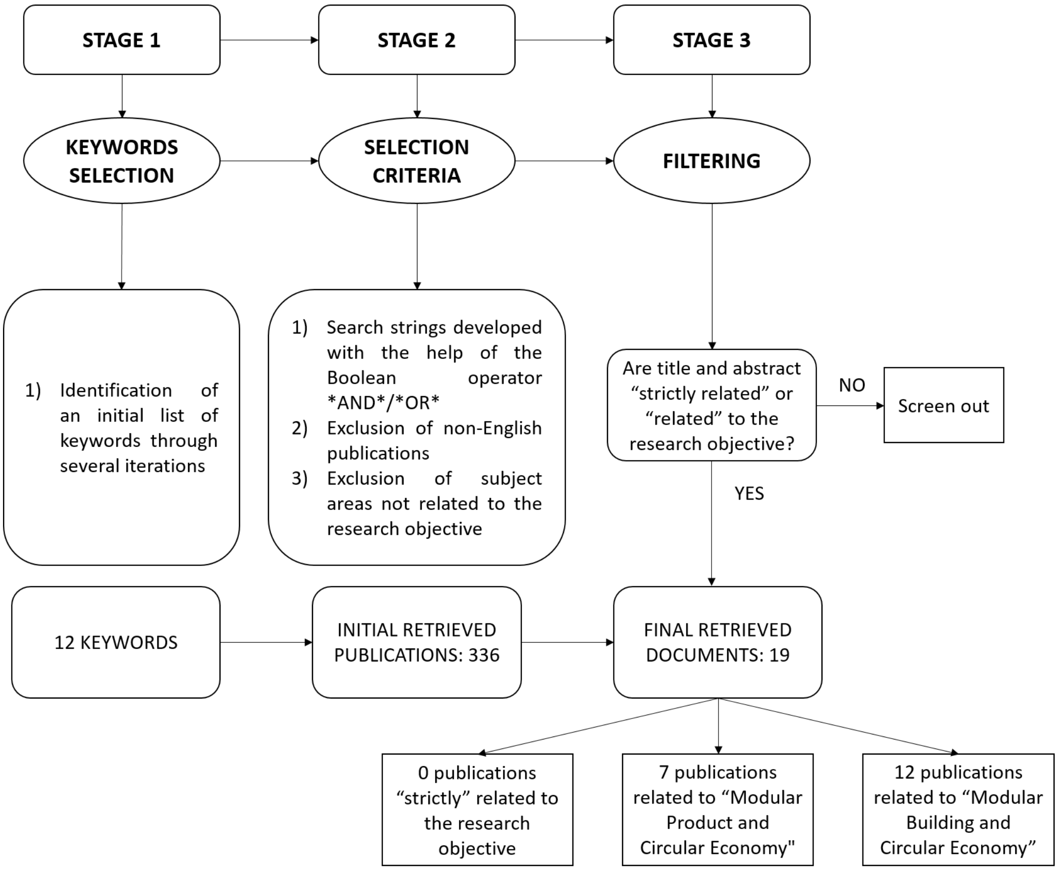

Figure 3: Selection process – Section A. Layout adapted from Di Maddaloni and Davis (2017)

In section B of the selection process, following discussions with experts, the publications were searched on the ARUP, KPMG, Laing O'Rourke, Burges Salmon, and Ellen MacArthur Foundation websites [‡] because leading in publishing freely available high-quality reports in relevant fields. Two keywords related to the research objective were used to search publications: "Circular Economy" and "Modular" (search date: 8/02/2019).

No one publication strictly related to the research objective was retrieved. Only ARUP (2016) shows the link between modularisation and circular economy but focusing on the building construction sector. Table 1 (in the appendix) reports the retrieved publications in Section A and Section B of the selection process.

[‡] ARUP is "an independent firm […] working across every aspect of today's built environment" (https://www.arup.com/our-firm). KPMG is "a global network of professional services firms providing Audit, Tax and Advisory services" (https://home.kpmg/cn/en/home/careers/who-we-are.html). Laing O'Rourke is "a privately owned, international engineering enterprise […]" (http://www.laingorourke.com/who-we-are.aspx). Burges Salmon is an independent UK law firm (https://www.burges-salmon.com/about-us/). Ellen MacArthur Foundation is a "UK-registered charity with a mission to accelerate the transition to a circular economy" (https://www.ellenmacarthurfoundation.org/policies).

Figure 3 presents the number of publications that highlighted the link between "modular product and circular economy" and "modular building and circular economy" per year.

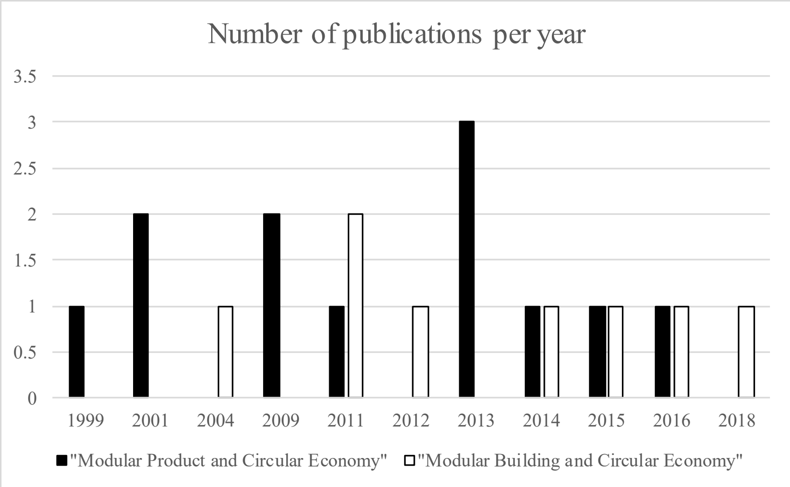

Figure 4: Number of publications per year

MODULAR ENERGY INFRASTRUCTURE AND CIRCULAR ECONOMY: LESSON LEARNED

Remarkably, there are no publications focusing on the link between circular economy and modularisation in energy infrastructure. Few publications focus on this link in the building construction sector, and several publications point out the link between circular economy and modular product. Following the procedures from Section 2, the authors scrutinised in detail 20 publications (listed in the appendix) showing several concepts and practises related to the link between modularisation and circular economy. 12 publications refer to modular products, and 8 refer to the building construction sector. This section summarises the key concepts and practices highlighted in these 20 publications.

Modular building

- Reduction of the construction and demolition waste

Prefabrication can reduce construction and demolition waste Cheng et al. (2015); however, the authors do not explain the reasons. ARUP (2016) points out that modularisation, coupled with the design for disassembly, allows easy changes to the structure reducing the construction waste. Furthermore, modularisation, using 3D print and additive manufacturing, might reduce waste and shorten the construction schedule, saving £800m per year ARUP (2016). Li et al. (2014) present a model to evaluate the impact of prefabrication on construction waste, and validate the model using data from a construction project in Shenzhen (China). The analysis reveals the possibility of reducing construction waste using prefabrication instead of the conventional method and points out that the policy of increasing the subsidy for prefabrication of square meter strongly influences the promotion of prefabrication adoption and construction waste reduction with respect to tax income benefits.

- Achievement of the closed-loop building material cycle

Lehmann (2011b), (2011a); Pulaski et al. (2004) highlight the importance of the design for deconstruction/disassembly to achieve the closed-loop building material cycle. They also recognise the merit of modularisation in improving the deconstruction fostering the closed-loop material cycle. Furthermore, simple and standardised connections simplify the assembly and disassembly process. However, the authors do not provide details about the reasons and the effective implications of modularisation.

- Reduction of the lifecycle energy requirements

Prefabrication can reduce the lifecycle energy requirement. In particular, Aye et al. (2012) assess the lifecycle energy requirements of three different forms of construction for a residential building: prefabricated timber construction, prefabricated steel construction, and conventional concrete construction. Although the energy embodied in the prefabricated steel building results up to 50% higher than the conventional one, the reuse of the main steel structure of the modules and other components in a new building could determine a saving of the 81% of that energy. Reusing allows a reduction of the required space for landfill and the reduction of the use of virgin raw materials.

- Design toward adaptability

Design toward adaptability is one of the strategies for reducing material consumption in the building construction sector. Modular design and standardisation represent two key strategies toward adaptability Minunno et al. (2018). The authors do not provide other details about the impact of modular design and standardisation on the design toward adaptability.

Modular product

The modular design could improve performances in disassemblability, maintainability, upgradability, reusability, and recyclability Hata et al. (2001); Umeda et al. (2009). A design characterised by modules that can be assembled in different ways allows applying the required changes without rendering a solution obsolete Schulte (2013). However, several factors need to be considered to achieve optimal performances in terms of circular economy.

- Assessment in the early design stages

The link between modular design and the increased performances in the lifecycle stages is achievable only if the lifecycle options of the components are evaluated and determined since the early product design stages Umeda et al. (2009). The key points about the module design in a “circular economy” perspective are:

- The design of a modular product should avoid joining components made of different materials, and components with different physical life to facilitate the lifecycle options Hata et al. (2001). This latter point is also stressed by Yan and Feng (2014) who stress that a different approach would determine a waste of resources.

- Common modules in a product family and the inclusion of the likely reusable components in the same module facilitates the reuse Hata et al. (2001); Liu (2013). Furthermore, technological stability, functional upgradability, long life, ease of quality assurance, and ease of cleaning and repair are key module characteristics to increase the possibility of reuse Kimura et al. (2001).

- The inclusion of the likely upgrading components in the same module could enable the module to be replaced as a whole unit facilitating the upgrading process Liu (2013).

- The inclusion of not recyclable or reusable components having the same processing method in the same modules could facilitate the processing process Liu (2013).

- Modular products might include electronic monitoring to predict the expire date of the modules according to their use Allwood et al. (2011).

- Different modularisation methods and different goals

Each modularisation method of the product has one or more goals (e.g. schedule reduction, sustainability, product variety, etc.). According to Halstenberg et al. (2015), there are two groups of modularisation methods: "methods for single product modularization" and "methods for product family modularization". The first group has two main steps: conduct a single decomposition and create a single product architecture. The second group also has two steps: conduct multiple decompositions and aggregate the elements to a family product architecture.

Halstenberg et al. (2015) present the "Target- oriented Modularization Method" which allows defining product architecture based on specific goals. However, the authors only provide the generation method of different product architecture alternatives (generated according to similarity and dependency analysis) and do not provide details about choosing goals and the related implications.

Furthermore, Ji et al. (2013) highlight that the "material reuse modularisation" and "technical system modularisation" are two different concepts. The "material reuse modularisation" is not only an expansion of "technical system modularisation". On the contrary, modules determined by the "material reuse modularisation" might be inconsistent with the modules determined by the "technical system modularisation". The authors present a decision model that considers both modularisation measures.

According to Schischke et al. (2016), there are different levels of modularisation and different related conventional environmental design strategies. Focusing on smartphones with a modular design, Schischke et al. (2016) point out five levels of modularization (Add-on, Material, Platform, Repair, Mix & match) and, when applicable, the related conventional environmental design strategies (e.g. Ease of maintenance and repair, Disassembly and reassembly, Upgradability and adaptability). The Add-on modularisation main characteristic is the attachment of peripheral functionalities to a core (e.g. display-CPU). The possibility to separate some materials (e.g. batteries) easily is the main characteristic of material modularisation. In the case of platform modularisation, products are configured for a range of individual specs. The possibility to exchange the key components easily is the main characteristic of repair modularisation. Finally, the Mix & match modularisation level, which considers specs for all modules, standardised module interfaces, hot-swapping, maximum flexibility and includes repair modularisation presents the strongest correlation with the design for circular economy strategies Schischke et al. (2016).

- Undergoing the reuse or recycling process "directly"

The environmental load and the cost of logistics and recovery processes reduce when the module can undergo the reuse or recycling process directly (without the need for disassembly in components). This is a result of the methodology presented by Umeda et al. (2009) and applied in the evaluation of the environmental load of two different modular structures. Furthermore, Fukushige et al. (2009) present a modular design method based on the lifecycle scenario. The method considers modules characterised by components suitable for the same lifecycle options permitting modules undergoing the lifecycle options without disassembly, and evaluate the modular structure in terms of resource efficiency.

- Modularisation is a key enabler of the inverse manufacturing

A lifecycle simulation system can evaluate the effect of modular design in a "circular economy" perspective. Nonomura and Umeda (1999) presents and applies a life-cycle simulation system showing that an appropriate modular design is a key enabler of inverse manufacturing.

CONCLUSION AND A WAY FORWARD

Developing sustainable infrastructure leveraging the principles of circular economy is essential for the energy sector. Traditional stick-built energy infrastructure have a lifecycle predetermined by the lifetime of their components. Modular infrastructure might be reconfigurable and extend/adapt their lifecycle decoupling the life of the infrastructure from their modules. In a wider perspective, circular economy would be a cornerstone of this novel strategy to manage sustainable modular infrastructure.

This paper, through an SLR, aims to identify "what we know" about the link between circular economy and modular energy infrastructure. Remarkably, despite the growing interest of policymakers, academics and industry in both circular economy and modularisation, there are no publications focusing on the link between circular economy and modularisation in the energy sector. State of the art includes few publications highlighting this link in the building construction sector, and several publications pointing out the link between a modular product and circular economy. There are no publications bringing the ideas of energy infrastructure, modularisation and circular economy together.

The results of the literature review analysis suggest that modularisation could improve performances in disassembly, maintainability, upgradability, reusability, and recyclability. The inclusion of components with similar characteristics (e.g. same likelihood of reuse or recycling) in the same module facilitates the achievement of the circular economy goals. Furthermore, modularisation could reduce the construction and demolition waste and improve the deconstruction process. Modularisation could also reduce the lifecycle energy requirement and material consumption.

In the case of a modular product, there are several modularisation methods, and each method is related in a different way to circular economy. A precondition to achieving the expected advantages of modularisation in a "circular economy" perspective is the assessment of the lifecycle options of components/modules in the early design stages. Furthermore, several methods that allow evaluating the impact of modularisation in a "circular economy" perspective have been developed already at an academic level, less at an industrial level.

The stakeholders involved in the planning and delivery of energy infrastructure should familiarise with these concepts and practises to develop sustainable energy infrastructure reducing waste, CO_2 emission, minimising the use of raw materials, etc. Furthermore, the stakeholders should evaluate the preconditions, enabling factors, and barriers related to the design of modular energy infrastructure in a "circular economy" perspective.

The gap in knowledge about circular economy in modular energy infrastructure is a strong motivation for doing further research.

This paper paves the way to a number of future research opportunities. Among the others, the following research questions are, according to the authors, the most relevant.

- Research questions dealing with legislation: What are the implications of the link between circular economy and modular energy infrastructure from a legal point of view? What are the consequences if the legislation changes and a module cannot be used anymore? In a wider perspective, what is the relationship among countries with different legislation about energy infrastructure? To what extent regulatory harmonisation between countries could promote the benefit of modularisation in a circular economy perspective?

- Research questions dealing with innovation: Could innovation be a barrier of the link between circular economy and modularisation? Could a new technology make unworthy the re-use of the module?

- Research question dealing with module lifting and transportation: Module lifting and transportation is one of the critical points of modularisation. In the case of a modular energy infrastructure designed to exploit the benefits of modularisation fully in a circular economy perspective, module lifting and transportation could be more critical than a "traditional" one. How are module lifting and transportation exactly related to the link between modularisation and circular economy?

- Research question dealing with the value of resources/ geographical inhomogeneity: The value of a module could be different according to the country because the circumstances could be different (e.g. legislation, labour cost). To what extent this disparity could address the issues related to innovation and legislation?

- Research question dealing with standardisation of the interfaces: A precondition of the link between modularisation and circular economy is the standardisation of interfaces. Who should be responsible for the standardisation of the interfaces?

- Research questions dealing with the end of life cost: Which is the impact of the link between modularisation and circular economy on the end of life cost? Could it decrease?

Furthermore, another area of future research concerns investigating whether the developments of emerging technologies such as the Internet of Things, digital twin and cyber-physical systems could foster the development of energy modular infrastructure in a "circular economy" perspective.

Finally, "learning the right way to fully exploit the benefits of modularisation from a circular economy perspective" leveraging the experience accumulated over the year in other sectors could be a key success factor to develop sustainable modular energy infrastructure.

APPENDIX

Table 1: Publication/Link highlighted

Publication/Link highlighted	Modular Product and Circular Economy	Modular Building and Circular Economy
Nonomura and Umeda (1999)	X	
Hata et al. (2001)	X	
Kimura et al. (2001)	X	
Pulaski et al. (2004)		X
Fukushige et al. (2009)	X	
Umeda et al. (2009)	X	
Allwood et al. (2011)	X	
Lehmann (2011a)		X
Lehmann (2011b)		X
Aye et al. (2012)		X
Ji et al. (2013)	X	
Liu (2013)	X	
Schulte (2013)	X	
Li et al. (2014)		X
Yan and Feng (2014)	X	
Cheng et al. (2015)		X
Halstenberg et al. (2015)	X	
ARUP (2016)		X
Schischke et al. (2016)	X	
Minunno et al. (2018)		X

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REFERENCES

Allwood, J.M., Ashby, M.F., Gutowski, T.G., Worrell, E., 2011. Resources , Conservation and Recycling Material efficiency : A white paper. Resour. Conserv. Recycl. 55, 362–381.

ARUP, 2016. The Circular Economy in the Built Environment.

Aye, L., Ngo, T., Crawford, R.H., Gammampila, R., Mendis, P., 2012. Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules. Energy Build. 47, 159–168.

Azhar, S., Lukkad, M.Y., Ahmad, I., 2012. Modular v. Stick-Built Construction : Identification of Critical Decision-Making Factors, in: 48th ASC Annual International Conference Proceedings.

Bondi, A., Magagnini, A., Mancini, M., Micheli, G.J.L., Travaglini, A., 2016. Supporting Decisions on Industrial Plant Modularization : A Case Study Approach in the Oil and Gas Sector, in: International Conference on Industrial Engineering and Operations Management. Kuala Lumpur, pp. 742–753.

Carelli, M., Garrone, P., Locatelli, G., Mancini, M., Mycoff, C., Trucco, P., 2010. Economic features of integral, modular, small-to-medium size reactors. Prog. Nucl. Energy 52, 403–414.

Cheng, J.C.P., Won, J., Das, M., 2015. Construction and Demolition Waste Management using BIM technology, in: Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction. Perth, Australia.

De La Torre, M.L., 1994. A review and analysis of modular construction practices. Lehigh University.

Di Maddaloni, F., Davis, K., 2017. The influence of local community stakeholders in megaprojects: Rethinking their inclusiveness to improve project performance. Int. J. Proj. Manag. 35, 1537–1556.

European Environment Agency, 2017. Circular by design - Products in the circular economy, EEA Report, No. 6/2017.

EY, 2016. Small modular reactors - Can building nuclear power become more cost-effective?

Fukushige, S., Tonoike, K., Inoue, Y., Umeda, Y., 2009. Product Modularization and Evaluation Based on Lifecycle Scenarios, in: Proceedings of the 5th International Conference on Leading Edge Manufacturing in 21st Century, LEM 2009.

Ghenai, C., 2012. Life Cycle Analysis of Wind Turbine, in: Sustainable Development - Energy, Engineering and Technologies - Manufacturing and Environment.

GIF/EMWG, 2007. Cost estimating guidelines for generation IV nuclear energy systems.

GIF/EMWG, 2005. Cost estimating guidelines for generation IV nuclear energy systems.

GWEC, 2019. Global Statistics [WWW Document]. URL http://www.solareb2b.it/wp-content/uploads/2016/06/SPE_GMO2016_full_version.pdf (accessed 2.22.19).

Halstenberg, F.A., Buchert, T., Bonvoisin, J., Lindow, K., 2015. Target-oriented Modularization– Addressing Sustainability Design Goals in Product Modularization Friedrich. Procedia CIRP 29, 603–608.

Hata, T., Kat, S., Kimura, F., 2001. Design of Product Modularity for Life Cycle Management, in: 2nd International Symposium on Environmentally Conscious Design and Inverse Manufacturing. pp. 93–96.

IAEA, 2019. Power Reactor Information System [WWW Document]. URL https://pris.iaea.org/PRIS/home.aspx (accessed 2.22.19).

Ji, Y., Jiao, R.J., Chen, L., Wu, C., 2013. Green modular design for material efficiency : a leader-follower joint optimization model. J. Clean. Prod. 41, 187–201.

Kimura, F., Kato, S., Hata, T., Masuda, T., 2001. Product Modularization for Parts Reuse in Inverse Manufacturing. CIRP Ann. 50, 89–92.

Lehmann, S., 2011a. Optimizing Urban Material Flows and Waste Streams in Urban Development through Principles of Zero Waste and Sustainable Consumption. Sustainability 155–183.

Lehmann, S., 2011b. Resource Recovery and Materials Flow in the City: Zero Waste and Sustainable Consumption as Paradigms in Urban Development. Sustain. Dev. Law Policy 11.

Li, Z., Qiping, G., Alshawi, M., 2014. Measuring the impact of prefabrication on construction waste reduction : An empirical study in China. Resour. Conserv. Recycl. 91, 27–39.

Liu, L., 2013. The exploration of recycling design of furniture products based on structure. Adv. Mater. Res. 695–607, 44–48.

Mignacca, B., Locatelli, G., Alaassar, M., Invernizzi, D.C., 2018. We never built small modular reactors (SMRs), but what do we know about modularization in construction?, in: 26th International Conference on Nuclear Engineering, ICONE26. London,United Kingdom.

Minunno, R., O'Grady, T., Morrison, G.M., Colling, M., Gruner, R.L., 2018. Strategies for Applying the Circular Economy to Prefabricated Buildings. Building.

Molina-Moreno, V., Leyva-Díaz, J.C., Sánchez-Molina, J., Peña-García, A., 2017. Proposal to foster sustainability through circular economy-based engineering: A profitable chain from waste management to tunnel lighting. Sustain. 9.

Nonomura, A., Umeda, Y., 1999. Life cycle simulation for the inverse manufacturing, in: Proceedings First International Symposium on Environmentally Conscious Design and Inverse Manufacturing. IEEE, Tokyo, Japan.

Preston, F., Lehne, J., 2017. A Wider Circle? The Circular Economy in Developing Countries A Wider Ci.

Pulaski, B.M., Hewitt, C., Horman, M., Guy, B., 2004. Design for Deconstruction. Mod. Steel Constr. 44, 33–37.

Sainati, T., Locatelli, G., Brookes, N., 2017. Special Purpose Entities in Megaprojects: empty boxes or real companies? Proj. Manag. J. 48.

Schischke, K., Proske, M., Nissen, N.F., Lang, K., 2016. Modular Products : Smartphone Design from a Circular Economy Perspective Modularity, in: Electronics Goes Green 2016+ (EGG). Berlin, Germany, pp. 1–8.

Schulte, U.G., 2013. New business models for a radical change in resource efficiency. Environ. Innov. Soc. Transitions 9, 43–47.

Umeda, Y., Fukushige, S., Tonoike, K., 2009. Evaluation of scenario-based modularization for lifecycle design. CIRP Ann. - Manuf. Technol. 58, 1–4.

Upadhyay, A.K., Jain, K., 2016. Modularity in nuclear power plants: a review. J. Eng. Des. Technol. 14.

Vanner, R., Bicket, M., Withana, S., Brink, P. Ten, Razzini, P., Dijl, E. Van, Watkins, E., Hestin, M., Tan, A., Guilche, S., Hudson, C., 2014. Scoping study to identify potential circular economy actions , priority sectors, material flows and value chains.

Yan, J., Feng, C., 2014. Sustainable design-oriented product modularity combined with 6R concept : a case study of rotor laboratory bench. Clean Techn Env. Policy 95, 95–109.

RISK MANAGEMENT OF RAIL INFRASTRUCTURE MEGAPROJECTS

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The Australian government is providing significant investment in infrastructure, with a projected $75 billion to be spent over the next 10 years. This in turn has stimulated a number of complex rail infrastructure megaprojects to meet election promises and end-user demands. Megaproject expenditure generally exceed $1 billion, having a project lifecycle that can extend beyond five years. They are inherently complex with technical challenges and a strong stakeholder interest, generating high levels of uncertainty. It is well documented and researched that over 60% of megaprojects fail due to schedule overruns and cost blowouts. The risks associated with major infrastructure projects are therefore substantial. However, despite risk management being a key factor in the successful delivery of megaprojects, this remains one of the least developed research areas in the industry. With the state of Victoria's population being forecast to reach 9.4 million over the next 30 years, infrastructure will continue to play a key long-term role in both servicing the population and supporting the regional economy. This highlights the need for effective and successful delivery of such projects, with cost overruns implying a wastage of public resources that could have been otherwise used for productive purposes elsewhere. This paper examines the key attributes for effective risk management to facilitate the successful delivery of rail infrastructure megaprojects. This review considers the documented reasoning for the perceived success and failure of such endeavours, whilst considering the specific risk profile of the delivery of rail infrastructure projects in Victoria. The research approach adopted includes a literature review of academic papers, government reports and interviews conducted with leading industry professionals. The findings from the results identifies selected drivers for enhancing risk management effectiveness, which in turn aim to improve the likelihood of successful delivery of rail infrastructure megaprojects.

Keywords: Megaprojects, Rail Infrastructure, Risk Management, Success and Failure, Victoria.

INTRODUCTION

In the 2018 to 2019 budget, the Australian Government committed $75 billion towards investments in the transport sector towards infrastructure related projects over a 10 year period (Treasury, 2019). This significant investment has resulted in a promise to modernise rail infrastructure through the upgrading of existing networks and the development of new capital projects. Many of these committed improvements such as the Melbourne Metro Rail Project, are highly complex and meet the accepted criteria of megaproject classification. A megaproject is frequently defined by a capital investment of over $1 billion and characterised by complex engineering interfaces, high level of uncertainty, significant stakeholder interest, strong political foci, and a project period extending beyond five years (Irimia-Dieguez, et al., 2014).

Current research indicates that over 60% of megaprojects fail due to cost, schedule overruns and failed procurement (Misic & Radujkovic, 2015: Beckers, et al., 2013). Whilst these failures are well documented, there is less literature and academic consensus as to how success can be defined or identified (Shenhar & Holzmann, 2017). Despite megaprojects being highly complex and at high risk of failure, there will always be a need to deliver these types of venture, as insufficient or underdevelopment of infrastructure presents a significant barrier for economic growth and social improvement.

Infrastructure megaprojects are becoming more complex, ambitious and subject to ever increasing public scrutiny. Thus, it is important that these types of project are given the appropriate long-term risk strategy that they necessitate in order to increase the likelihood of success and reduce uncertainty over the lifecycle of the project delivery.

Delivery of Rail Megaprojects in Australia (A Victorian Perspective)

Over the past 10 years Victoria has had a steady portfolio of significant rail infrastructure projects; notably the successful delivery of Regional Rail Link (RRL) Project in 2015. RRL is seen by many within the sector as Victoria's flagship rail project, demonstrating local industry capability and availability of resources to successfully deliver a significant rail megaproject (Greaves, 2018). Following the successful completion of RRL project, Victoria has recently entered what could be termed a 'golden age' of rail infrastructure investment, with many labelling the current portfolio of investment a 'rail boom'.

Victoria has received a significant proportion of this year's allocated governmental budget, with a projected average of $9.6 billion to be provided annually over the next four years (Cabinet, 2018). Current commitments and planned funding in Victoria include: Melbourne Airport Rail Link ($5 billion); Melbourne Metro Tunnel ($11 billion) and Melbourne to Brisbane Inland Rail ($9.3 billion). To support the delivery of these projects the State Government established the Major Transport Infrastructure Authority (MTIA) comprised of project teams. These include the Level Crossing Removal Authority (LXRA) which is responsible for the removal of over 75 level crossings by 2025, and Rail Projects Victoria (RPV) that is responsible for delivering the Melbourne Metro Project, Regional Rail Revival, the fast rail between Geelong and Melbourne, and the future Melbourne Airport Rail Link.

As a result of this expansion, the Victorian rail industry has generated job market growth, stimulated the regional economy and provided a clear plan to identify and resolve infrastructure deficiencies that are in urgent need of resolution. However, as previously noted, megaprojects are inherently risky and as dubbed by Flyjberg, are subject to the much too commonly observed pattern of the "The Iron Law", 'overtime and over budget, over and over again' (Know 2017). This in turn potentially magnifies the already high-risk nature of megaprojects, subsequently exposing any weaknesses in Victoria's capacity and capability to deliver complex rail infrastructure projects.

The risks associated with major infrastructure projects are substantial (Flyvberg, et al., 2003). Effectively managing risks is an important factor assuring the success of megaprojects. Despite the crucial role risk management plays, it remains one of the least developed research areas (Irimia-Dieguez, et al., 2014). This paper seeks to explore some of the opportunities available to enhance the likelihood of rail megaprojects successfully being delivered within Victoria.

RESEARCH APPROACH

This paper is written from the perspective of the private industry during the delivery phase of a megaproject. This paper seeks to utilise feedback from industry professionals during this phase of expansion in transport infrastructure investment. The research approach for this paper was informed using a blend of literature published in academic journals, government papers and guidelines. Qualitative data from six interviews[§] conducted with experienced industry professionals has also been used to inform the discussion within the analysis.

The objective of the interviews was to obtain an insight into the perspectives of leading industry professionals, which in turn may provide recommendations for enhanced risk management techniques on rail infrastructure megaprojects at a national level.

Data Collection

Interview respondents were asked a mixed set of semi open-ended questions, examples include:

- Why do you think megaprojects continue to fail?
- Do you believe that the success of a megaproject is predetermined before it starts? If so, why?
- What do you think of Australia's track record with respect to delivering rail infrastructure projects? And what brings you to this conclusion?
- What do you feel the rail industry within Australia does well from an infrastructure project delivery perspective?

[§] It is acknowledged that the number of interviews conducted does not provide the level of data required for academic weighting. However, for the scope of this industry stream paper it provides an insight into an industry viewpoint in the current environment.

- What do you feel the rail industry within Australia should do to improve infrastructure project delivery?
- Based upon your experience of delivering megaprojects in Australia, do you feel there is an integrated approach to risk management?

Interviewees were from an array of disciplines and organisations that have been involved in the delivery of rail infrastructure projects in Victoria. A total of 10 semi-structured interviews were conducted with professionals from a variety of backgrounds. The interviewees included, Project Managers, Project Directors, Operations Managers, and Major Project Executives. During the interview process the interviewer used personal judgement to clarify responses and discuss topics in more details.

RISK MANAGEMENT

Risk management is about identifying potential variation from what is planned or desired and managing these to maximise opportunity, minimise loss and improve decision outcomes. As such risk assessment is an essential part of strategic planning processes. In turn, this supports well-informed managerial decisions and a risk management framework developed to retain a "no surprise" project operation status (Zarei, et al., 2017).

Preparing how to cope with risk can be an extremely complex task, particularly on a megaproject. In order to properly plan for effective risk management throughout the lifecycle of the project, it is important at the start of the contract to develop a robust Risk Management Plan (RMP) (Flyvberg, et al., 2003). The RMP should document the assumptions, strategy, policy and tools to deliver the risk management function (Szymanski, 2017). Implementing a risk management plan will formalise the governance of how risks will be regulated and actioned during the project delivery. This in turn will provide structure to the risk management processes and establish the foundations for mitigating risk and uncertainty during project delivery.

A risk-based approach to project delivery is the cornerstone of effective project management and is an essential part of an organisation's strategic planning process to make informed managerial decisions (Zarei, et al., 2017). It is now common convention that projects adopt a standard approach to identifying threats and opportunities, often in a workshop environment (Ellis, 2014). A standard risk management framework is illustrated in the Figure 1 (below). This simple process presents an effective way to determine key steps (taken from ISO 31000 – Risk Management Principles and Guidelines).

Risk Management Steps

- **Risk Identification:** The risk assessment process is undertaken to identify where, when, why and how events or actions could prevent, degrade, delay or enhance the achievement of the project's objectives.
- **Risk Analysis:** Each risk is evaluated in terms of the likelihood that the risk will occur with consideration of the potential consequences. Risk analysis is based on a combination of qualitative and semi-quantitative methods to attribute ratings for each risk and the associated commercial impacts (e.g. technical,

commercial and safety etc). When performing risk analysis, reliable sources of information are invaluable, such as: past records; previous risk assessments; experiences with similar issues; industry best practice; subject matter experts; published literature; including specialist services that should be used when appropriate to minimise subjective bias.

- **Risk Evaluation:** The evaluation process is an important step to prioritise risks, consider options to determine what action is required, and where necessary escalate extreme and high risks through the agreed reporting lines.
- **Risk Treatment:** Action taken to manage the risk when required. It is a decision made during the evaluation.
- **Risk Strategy:** Define a clear strategy to address the project's objectives with respect to risk management. The advantages of having a clear risk management strategy is to instil a common understanding of risk management, the activities to be pursued to enhance the framework, and the requirements to achieve this (Victoria, 2016).

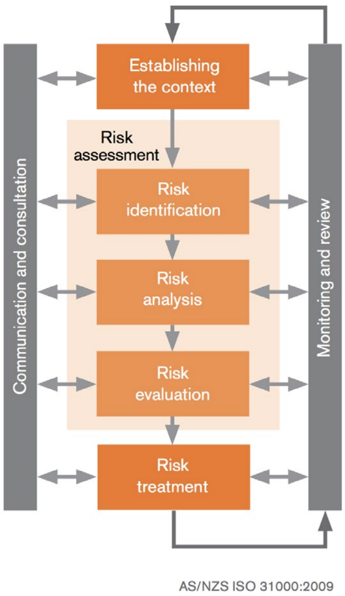

***Figure 1** - Risk Management Framework*

(after ISO31000 – Risk Management Principles and Guidelines).

Megaprojects are not just enhanced versions of conventional smaller projects, they are completely different in terms of their levels of aspirations, stakeholder involvement, duration, complexity and impact (Shenhar & Holzmann 2017). Thus, there is a strong argument that the application and robustness of risk management practices should accommodate this. Therefore, further risk management techniques are discussed below, based upon themes identified during interviews and / or common consensus pertinent journals, industry reports and government audit reports.

Leadership and Risk Awareness

"*Strong leadership and clear direction from leaders*"

Interview Response

During interview discussions 'leadership' was commented upon the most with respect to the factors that influence the likelihood of delivering a successful project. This is further complemented by research conducted by Know, et al., (2017), who proposes that delivering a large project not only requires a combination of technical skills and experience, but also strong measures of motivation, innovation and leadership. A key finding of the research indicates that project leadership gains greater importance with increasing project size and complexity, which emphasises the importance of this attribute for megaproject realisation.

Thus, in support of the application of risk management techniques, there is a growing focus on driving behaviours at the project delivery phase to implement techniques and achieve a best for project outcome. Ellis (2014) suggests that human factors are a major cause of projects not achieving their objectives and suggests that causal factors include lack of project leadership and poor culture with respect to risk management.

Research conducted by Know, et al., (2017) suggests the following leadership attributes improve the likelihood of a project being successfully delivered:

1. **Lead as a business, not a project:** A megaproject is more akin to building a business than purely executing a construction project, requiring CEO-level leadership and judgement to address a broad range of organisational issues.
2. **Take full ownership of outcomes:** The project owner needs to maintain full accountability for delivery. They must remain well informed throughout and be ready to step in to make tough decisions in a timely manner.
3. **Make your delivery agent successful:** Owners and delivery agents work best as a business partnership with a mindset of 'we win together or lose together'. Productive contractor-owner relationships are based on mutual trust and joint problem solving.
4. **Trust your processes but know that leadership is required:** Processes alone will not resolve every challenge on a megaproject. Leaders should trust and enforce the appropriate process but recognise their benefits and limitation.

The Right Leadership

"A well-balanced professional team led by a Project Director who ensures a holistic and integrated outcome is achieved for the project".

Interview response

In support of having strong leadership is was noted during an interview that there is a perceived tendency to fill senior leadership roles with professionals from an engineering background. In turn it was suggested that this drives a cascade behaviour where the project leaders will employ other engineering professionals for leadership roles that do not require an engineering background. The interviewee believed there is a perception within the industry that those from an engineering background will be better placed to manage risks on rail infrastructure megaprojects.

Within the domain of technical project management, there has been an increased focus on non-technical aspects in the execution of technical projects (Thite, 1999). Muller, et al., (2012) conducted research which suggests that the manager's leadership style influences the performance of the organisation and that different leadership styles should be employed as appropriate to the context of the project.

Risk Culture

"Establish an experienced team who are well integrated and aligned with the project objectives"

Interview response

The establishment of a sound risk management framework is fundamental if a megaproject is to succeed. However, the human behaviour aspect is just as important to achieve successful implementation and alignment to the risk avoidance processes. During the interview discussions there was a strong correlation with this theme that indicates risk 'culture' plays an important ingredient. In simple terms risk culture can be identified as the behaviours that generate the thought process and consequently handle risk, highlighting that the risk management framework must support the development of a positive risk culture (Victoria, 2016). Below are the three key components that are attributed to risk culture.

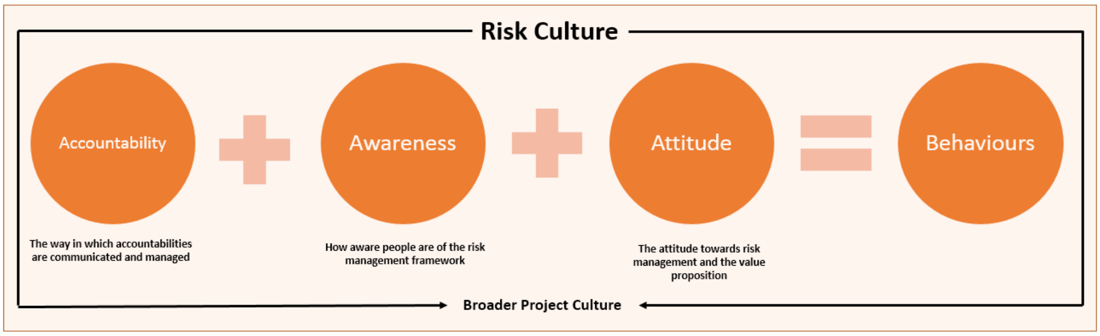

Figure 2 *- Risk Culture adopted from (Victoria, 2016).*

1. **Accountability:** The project leadership need to clearly define all team members accountability with respect to the application of risk management processes and appetite. If team members don't understand that they are responsible for the identification and mitigation of risks, the framework will be ineffective.
2. **Awareness:** All project team members need to be aware of the risk management framework and the project's objectives in relation to risk management.
3. **Attitude:** Effective project teams not only execute projects with a 'business as usual' mindset, but also share and understand the value of being a part of a unique 'once in a lifetime' experience (Know, et al., 2017). Thus, the attitude of individuals on the project will influence overall project behaviour towards risk management and its application.

A key factor in building a positive risk culture is to establish awareness relating to the above via effective communication. To achieve this at the design phase through to construction and commissioning the following techniques are recommended:

- 'Set the tone from the top'. The risk manager and senior leadership outline the expectations with respect to how risks are identified, managed and escalated.
- It is important that the tools used to capture and assess risk are reflective of the size and complexity of the project. For example, the traditional approach of using a 'spreadsheet' only accessible by the Risk Manager is ineffective. Thus, cloud-based tools accessible by all team members to record and manage risks is more effective.
- Complex tools should be avoided when seeking to encourage all team members to participate in the identification and recording of risks.
- A well-defined process should be established for transferring and closing risks to the residual risk owner.

Stakeholder Analysis

"Getting early integration, the right groups and stakeholders, then transferring this through the development, delivery and operation should be done to improve infrastructure project delivery"

Interview response

Rail infrastructure projects are particularly complex, dynamic and involve multiple interfaces impacted by numerous stakeholders (Patil et al, 2017). Many external stakeholders can introduce significant scope creep resulting in delays and cost overruns. Therefore, obtaining a clear understanding of stakeholder interest and influence is a key requirement to effectively manage these types of risks. Stakeholder analysis is a key tool in the risk management process. The method of identifying parties who are interested in the project and / or have the power to influence the objectives of the project can be achieved via stakeholder mapping. Figure 3 (below) is a suggested tool that can be used to map stakeholder interest and power in order to rank the stakeholder's influence.

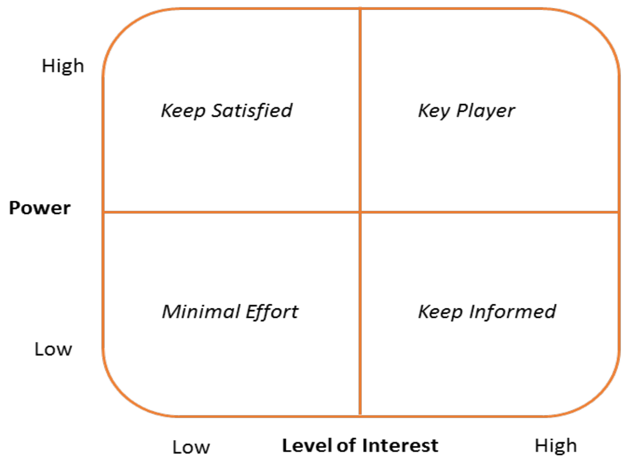

***Figure 3** – Stakeholder Mapping. After (Bourne & Walker, 2006)*

Flyvbjerg (2003) notes that the risk assessment process should involve stakeholders and consider their experience and expertise. Utilising the power / interest matrix (above), a simple but effective risk assessment process can be conducted. The first step in the process is to map stakeholders according to their interest in the project. The second step is to group the stakeholders in terms of power (i.e., their ability to influence project objectives and outcomes). Bourne and Walker (2006) suggest that the following stakeholder attributes should be considered in assessment process:

1. The stakeholder has limited influence but power to kill the project.
2. The project team is close to the project but has limited individual influence.
3. The project clients may be remote but have a significant influence group.
4. These stakeholders are relatively remote but influential.
5. Influential stakeholder close to the project (e.g. Project Manager).
6. This group of stakeholders has the influence and power to kill the project.

Risk Tools

Megaprojects regularly rely on multiple partners to form an entity, such as joint ventures. This results in multiple organisations with varied risk cultures and ways of accomplishing tasks rapidly merging together. Thus, the project often needs to quickly establish tools, processes and protocols to address these issues and ensure that the risk framework is of a robust enough standard to mature at the same cadence of the project.

The traditional approach of establishing a risk register on an excel spreadsheet that is 'owned' by the Risk Manager is a common trap for many projects. This situation can result in an environment where risks are not widely available to the project team, thus resulting in the risk not being proactively reviewed and managed. The opposing dilemma for a megaproject is the resistance to invest in robust risk management software that provides adequate accessibility and functionality for all staff involved.

Therefore, in order to effectively address this issue, it is recommended that readily available cloud-based tools, such as SharePoint can be customised to accommodate an environment where risks can be recorded, allocated a level and appropriated to discrete design deliverables, such as design packages. Below (figure 4) is an example of a risk input specially designed for a current rail megaproject in progress in Victoria.

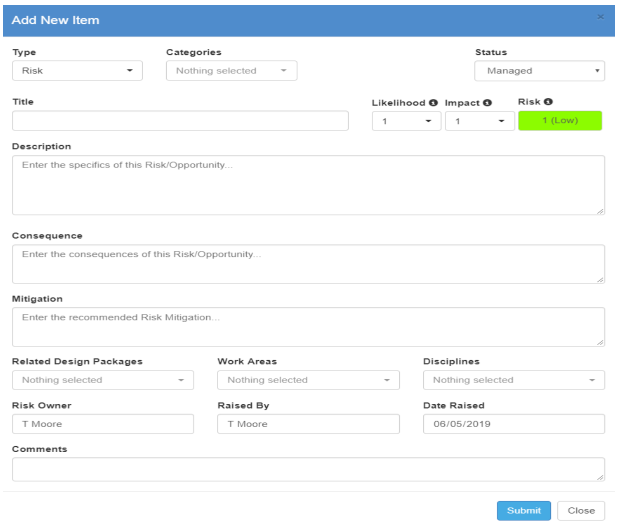

Figure 4 *– An example of recording a risk in a cloud base software.*

The benefits of employing a risk tool on readily available cloud-based software includes:

- The tool can be built to reflect the bespoke project requirements and risk management procedure.
- The development of the tool can be completed in a relatively quick time frame.
- All team members being given access.
- The team are provided with a clean and simple process to record and assess risks.
- The risks recorded via the software can be exported as individual risks and / or a consolidated spreadsheet in the form of a risk register.
- The categorisation of risks to inform and monitor of trends.
- The option to provide integration of the deliverables (e.g. design package) as part of the risk input process. This mechanism will automatically cross-reference the risk to the design package (or similar), thus promoting the package owner to address the agreed mitigation measures (e.g. in this instance, design controls).

Risk Monitoring and Reporting
The presentation of the risk profile is an effective tool to communicate to senior management the overall exposure of a project. This helps encourage a team to actively manage risks as opposed to managing data in a spreadsheet. A risk dashboard can be built in Excel using power queries or add-on software such as PowerBI. Below are some suggested metrics to be presented on a risk dashboard.

- Total number of risks and status
- Top 10 risks (or 25 %)
- New and emerging risks (during a specific timeframe)
- Risk types by category
- Heat map to illustrate the distribution of risks across the risk matrix (see figure 4).
- Supporting risk register.

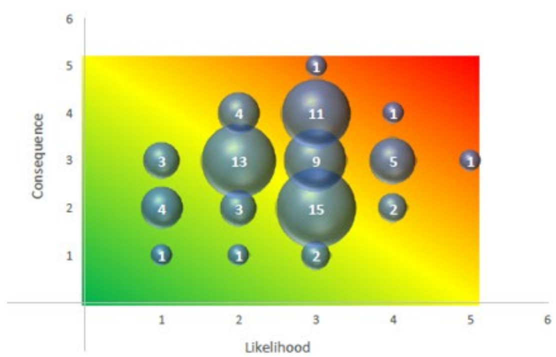

Figure 5 *- Example of a Heat Map.*

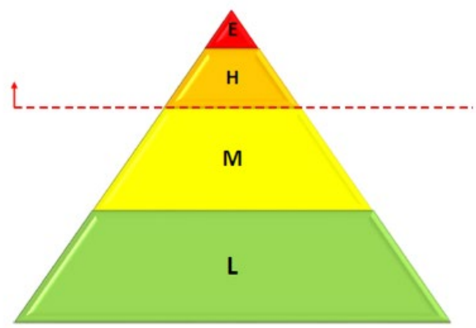

Figure 6 *– Escalation of Risks*

Figure 6 (above) provides a graphical demonstration of escalating risks based upon risk level. It is recommended that all extreme and high risks are escalated and reviewed by senior management to ensure adequate controls are implemented to effectively mitigate the risks.

Integrated Risk Management

> *"Effective risk management requires proactive involvement of managing risks at the engineer's level, upwards through to the senior management level. The Risk Manager coordination is essential and ensuring the process is implemented"*
>
> ***Interview response***

The application of conventional risk management techniques provides a sound framework to identify, define, assess and mitigate risks. However, the nature of a megaproject quickly brings together different organisations, stakeholders, and government entities who all have diverse approaches and appetites for risk. In turn this may lead to a potential situation where multiple project partners have disjointed risk management approaches. Furthermore, as previously noted, a megaproject is more akin to an organisation than a conventional project. Thus, it is important that a risk management framework is developed to accommodate the complexity of a megaproject.

To achieve this, it is recommended that rail megaprojects adopt an integrated approach to risk management during the lifecycle of the project. Upon exploring this issue during interviews there was no common consensus as to whether rail megaprojects in Victoria have evolved towards such an approach. However, all interview respondents felt that actively incorporating risk management processes was an important factor for improving the likelihood of a rail megaproject being delivered well.

Figure 7 (below) provides a proposed integrated risk management framework that can be applied to these types of high-risk projects:

Figure 7 - Integrated Risk Management. Adopted from (Beckers, et al., 2013).

- **Strategy** – At the start of the project a clear strategy should be established to determine appetite and risk return factors.
- **Governance** - Risk governance supports the improvement and performance for a project to achieve desired outcomes. Effective governance will guide required risk management behaviours and drive informed decision making (Victoria, 2016).
- **Decision Making** – Embed risk management principles into the decision-making process.
- **Culture** - The establishment of an effective risk control culture is extremely important for increasing the likelihood of the project in achieving its objectives. This will support an integrated approach to risk management throughout the lifecycle of the project.
- **Performance** – Adopt a proactive approach towards risk management by implementing a skill enhancement program for staff and undertaking a continual improvement approach (Plan-Do-Act-Check).

SUMMARY

Victoria is currently in a 'golden age' of rail infrastructure investment and delivery. The successful delivery of RRL was a key project that increased the State's confidence to deliver more complex, high risk rail infrastructure megaprojects. In turn, this has been a catalyst for Victoria to receive significant capital investment for new rail infrastructure development. The State government has responded by establishing RPV and LXRA to oversee the delivery of Victoria's portfolio of rail projects. In turn the infrastructure 'boom' has resulted in rapid job market growth and placed greater demand on limited skilled resources to deliver these projects.

The findings from this paper highlight that for risk management processes to be successful, it is important that the appropriate leadership in place which can cultivate a positive outlook towards risk management, embracing its long-term advantages. These observations are also supported by contemporary research in this field and reflected in the drive for megaprojects to establish clear cultures in respect of risk management.

The importance of stakeholder management was highlighted as an important attribute of effective risk management. In particular, the risk assessment process should include detailed stakeholder analyses to understand the level of interest and power that stakeholders may have upon the project's objectives. The application of stakeholder mapping will help inform this process and support the risk analysis of stakeholders.

It is recommended that rail megaprojects in Victoria should apply an integrated approach to the application of risk management. A suggested framework has been provided based on research and the themes identified in this paper. Furthermore, such an attitude for incorporating risk management should be supported by simple and accessible risk related tools that cultivate an environment where all project members are able to identify and govern risks on a day-to-day basis.

This paper highlights that rail infrastructure megaprojects should be treated more like an organisation than a conventional project. This philosophy will nurture a more sophisticated approach to risk management by implementing frameworks that are straightforward to apply, but also have the durability to deal with the high complexity encountered during the delivery of rail infrastructure megaprojects.

REFERENCES

Beckers, F. et al., 2013. A risk-management approach to a successful infrastructure project, s.l.: McKinsey & Company.

Bourne, L. & Walker, D. H., 2006. Visualising Stakeholders Influence - Two Australian Examples. Project Management Institute, pp. 5-21.

Cabinet, D. o. P. a., 2018. Victorian Infrastructure Plan, Melbourne: Department of Premier and Cabinet.

Deloitte, 2016. The Current and Future State of Victoria: a macro perspective, s.l.: Deloitte.

Ellis, T., 2014. How To Increase The Change of Project Success. s.l., Engineers Austalia Convention.

Flyvberg, B., Nils, B. & Rotherngatter, W., 2003. Megaprojects and Risk. Denmark: Cambridge.

Flyvbjerg, B., 2006. From Nobel Prize to Project Management: Getting Risks Right. Project Management Journal, pp. 5-15.

Greaves, A., 2018. Assessing Benefits from the Regional Rail Link Project, Melbourne: Victorian Government Printer.

Irimia-Dieguez, A., Shanchez-Cazorla, A. & Alfalla-Luque, R., 2014. Risk Management in Megaprojects. Issue 119, pp. 407-416.

Know, D. et al., 2017. The art of leadership: Delivering the world's largest projects, s.l.: McKinsey Capital Projects & Infrastructure Practice.

Misic, S. & Radujkovic, M., 2015. Critical drivers of megaproject success and failure. Procedia Engineering, Volume 122, pp. 71-80.

Muller, R., Geraldi, J. & Turner, J. R., 2012. Relationships Between Leadership and Success in Different Types of Project Complexities. IEEE Transactions on Engineering Management, 59(1), pp. 79-89.

Prater, J., Kirytopoulos, K. & Ma, T., 2017. Optimism bias within the project management context: A systematic quantitative literature review. International Journal of Managing Projects in Business, 10(2), pp. 370-385.

Shenhar, A. & Holzmann, V., 2017. The Three Secrets of Megaproject Success: Clear Strategic Vision, Total Alignment, and Adapting to Complexity. Project Management Journal, Volume 6, pp. 29-46.

Shenhar, A., n.d. s.l.: s.n.

Szymanski, P., 2017. Risk management in construction projects. Procedia Engineering, Volume 208, pp. 174 - 182.

Thite, M., 1999. Identifying key characteristics of technical projects. Leadership and Organisation, 20(5), pp. 253-261.

Treasury, A., 2019. Budget 2017-18. [Online]
Available at: https://budget.gov.au/2017-18/content/glossies/jobs-growth/html/jobs-growth-01.htm
[Accessed 31 March 2019].

Victoria, S. o., 2016. Victorian Government Risk Management Framework Practice Guide, Victoria: Victorian Managed Insurance Guide.

Wikipedia, 2019. Regional Rail Link. [Online] Available at: https://en.wikipedia.org/wiki/Regional_Rail_Link#Construction [Accessed 28 March 2019].

Zarei, H., Kin Peng Hui, F. & Duffield, C., 2017. The Risk of Power in Project Delivery: A Study of Large Victorian Public Infrastructure Projects. Journal of Risk Analysis and Crisis Response, 7(2), pp. 53-63

KNOWLEDGE MANAGEMENT IN MARINE PROJECTS THROUGH VALUE ENGINEERING PROTOCOLS, A REVIEW

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Marine construction projects are multidisciplinary and large scale. An important research gap in this area is not considering the definitive effect of employing knowledge in the early stages of these projects. This paper aims to highlight the role of knowledge as a catalyst for facilitating the performance eventuating from developed practical approaches, value engineering(VE) protocols in particular. Employing knowledge assists in the successful completion of marine projects through envisioning potential issues and employing knowledge in practice. This paper reviews the existing literature aimed at underlining the role of knowledge in the front-end phase of marine infrastructures as a specific domain. Findings from normative literature emphasise the great problem-solving potential of VE in different stages of projects' life cycles. These findings suggest that adopting VE protocols in line with knowledge during the front-end phase of construction projects facilitates information sharing, assists in developing practical ideas, improves project performance, and consequently ameliorates the efficiency of marine construction projects. This paper also identifies that knowledge assists marine projects when it develops a pathway for consideration of different design options and assists in developing ideas into practical approaches. The insights from the findings can be used as a guideline to advance efficiency, diminish design errors and untangle hinderances to marine construction.

KEYWORDS: project management, marine infrastructures, knowledge-based project, performance, value engineering

INTRODUCTION

Serpella et al. (2014) identify lack of knowledge as the principal cause of inefficiency in managing risk in construction projects. Serpella et al. (2014) believe that stakeholder satisfaction will not be achieved unless there is a robust approach that integrates knowledge and experience. It is expected that employing a robust approach will improve efficiency considerably.

The Project Management Institute classifies projects based on the predominant characteristics of the project, that is, on the factors of uniqueness, temporary tasks, complexity, resources, time and cost restrictions, multi-partnership, and uncertain scope of work. Ahmadi and Sutrisna (2018) consider project-management knowledge a tool for achieving the benchmarks set at the early stages of a project (e.g., benchmarks such as safety, quality, cost and duration). Likewise, Karami and Olatunji (2018b) outline uncertainty and design complexity as two unique attributes of projects conducted in marine environments. Uncertainty in design assumptions at the front-end phase leads to redesign problems, and consequently to time and cost overruns. Serpella et al. (2014) determine knowledge as a catalyst that is able to address these issues through a systematic approach that can predict, prevent and strategies by applying practical solutions.

However, Tan et al. (2010) and Ahmadi and Sutrisna (2018) argue that there continue to be challenged in relation to understanding the best way to situate knowledge and learning outcomes in the early phases of projects to advance efficiency and improve performance and benchmarks of time and cost. Focusing on marine construction projects as a unique context, this paper attempts to articulate the significance of the use of knowledge as a tool to advance efficiency and untangle issues in transferring knowledge by adopting value engineering (VE) protocols as a dedicated mechanism in the front-end phase of marine construction projects. The novelty of this paper lies in its introduction of knowledge as a success agent that can be highly valuable in marine construction projects when integrated with problem-solving approaches, particularly with VE. Given the limited statistics in the literature on the value of using knowledge in such projects, the paper identifies existing views and attempts to construct a framework that might help as a guide for the research community and the construction industry in improving the efficiency of marine construction projects. The proposed model illustrates the effectiveness of knowledge and VE integration.

LITERATURE REVIEW

Lampel et al. (2008) identify knowledge as an organisational advantage that requires frequent refreshing. The authors believe that knowledge enhancement can be gained through project deliverables and the technologies used in an organisation. Lampel et al. (2008) state that projects benefit from knowledge-based protocols at different stages. For example, construction projects benefit from steady improvement through advancing knowledge at the design stage. According to Todorović et al. (2015), efficiency in project management is greatly associated with integrating into different phases of a project the knowledge and lessons learnt from past project successes.

A great deal of literature ascribes knowledge-management issues in the context of projects to a lack of adequate learning protocols and precise reporting from previous projects (Hanisch et al., 2009), as well as to failing to record project procedures and functions (Bou and Sauquet, 2004). Similarly, Desouza and Evaristo (2006) and Koskinen (2004) state that deficiency in reporting, poor information sharing and insufficient employment of lessons learnt as other challenges relating to knowledge management in a project environment. The lessons learnt from previous projects are a fundamental factor in the knowledge management process. It is highly dependent on the scope and extent of the projects. Desouza and Evaristo (2006) identify particularity and extensive life cycle as two challenging variables in the development of lessons learnt from a project. Considering the uniqueness and large scale of marine projects, Tam (2012) emphasises lessons learnt as a significant source of knowledge that can improve efficiency in marine construction projects. Based on the dissimilarity of projects, Tam (2012) argues that this might not be exclusive, and the nuanced differences between different projects should always be considered.

Based on a literature review and considering Elena and Alfonso (2004), Disterer (2002), Hanisch et al. (2009) and Kang (2007), Todorović et al. (2015) outline the lack of research evidence relating to implementing systematic approaches to identify and use the knowledge gained from previous projects in future projects. Todorović et al. (2015) conclude that the principal challenges to managing knowledge in a project environment are the lack of protocols in data gathering and the deficiency in documentation and reporting.

Significance of knowledge in the design phase of marine projects

A great deal of literature highlights the importance of the constructive application of knowledge in improving project performance and stakeholders' satisfaction with construction projects, including those conducted in a marine environment. Ahmadi and Sutrisna (2018) describe construction as a knowledge-based industry. Based on evidence from construction management, employing knowledge creates innovation and advances efficiency, and not including knowledge in construction projects leads to project failure (Kamara et al., 2002). Tang and Bittner (2014) identify the marine environment as an extremely uncertain context in which to undertake construction projects. Addressing multiple technical issues in a safe and efficient manner demands a systematic approach for employing creative solutions based on knowledge and experience. According to Tang and Bittner (2014), employing a knowledge-based approach is more beneficial when applied during the early stages of a project. For example, Shekarchi et al. (2011) argue that inadequate arrangements for environmental consequences result from a knowledge deficiency in relation to corrosion mechanisms during the design stage. The authors identify corrosion in reinforcement bars as the main cause of destruction in marine infrastructures, and state that this problem must be considered at the very early stages of project design.

Evidence in the literature classifies knowledge into two categories: explicit and implicit knowledge. Buono (1996) describes explicit knowledge in construction projects as referring to recorded information, design specifications and drawings, and risk, cost and delay reports that can be archived in either paper or electronic form. Lin et al. (2006) describe implicit knowledge as referring to potential expertise and experience maintained in a format other than archived sources, for example, lessons learnt, experienced staff, interpersonal skills and other valuable resources. Both types of knowledge are vital in the successful completion of marine construction projects and are considered by academics as helpful tools in complex design phases. For example, Johnson and Tatum (1993) emphasise technical proficiency and lessons learnt as two necessary factors for efficient design in marine infrastructures. This enhances the organisational structure of the company in the long term (Karami and Olatunji, 2018c). Managing knowledge in the design phase is paramount. Lin et al. (2006) describe knowledge management in the design phase as referring to the process of generating, establishing, recording, monitoring, integrating and sharing knowledge.

Tam (2012) states that specialised design principles are required for the specific, unique attributes of marine construction projects. Tam (2012) also identifies design and construction contingencies as probable risk factors affecting marine construction projects, which is also acknowledged by Karami and Olatunji (2018b). The authors state that the multidisciplinary nature of marine construction projects and the concurrent collaboration of different experts in different fields are further unique attributes of marine construction projects. Samie (2016) argues that the inadequate interface of the disciplines involved in marine construction projects as an important cause of design errors.

Clough (2000) argue that developing an effective knowledge-management system will overcome all design-related issues in two ways. First, a knowledge-management system will help to identify and record modern technologies and procedures that help in the design phase of marine projects. This results in improvements in productivity, as confirmed by Carrillo and Chinowsky (2006) in a survey conducted on contractors in the United Kingdom. Second, implementing a knowledge-management strategy also facilitates the design phase of a project, and prevents problems with a redesign by using expert knowledge from previous projects. Thus, it is crucial to consider knowledge as a determinant factor in most activities related to construction projects (Lampel et al., 2008).

Marine construction and potential to adopt dedicated mechanisms

Karami and Olatunji (2018a) state that the particularity of marine construction projects refers to their requirement for exceptional capabilities and techniques to deal with the risks and uncertainties involved in such projects. These authors argue that marine construction projects are complex, and require precise consideration beyond the common approaches to construction projects. Johnson and Tatum (1993) also state that working in a marine environment is extremely challenging. Thus, achieving the ideal completion of multiple tasks in this high-risk and uncertain environment requires a great deal of technical knowledge specific to the unique attributes of marine construction projects (Tang and Bittner, 2014, Karami and Olatunji, 2018c). Johnson and Tatum (1993) conclude that marine construction constitutes a distinctive industry that often uses developed technologies such as pile drivers, offshore installations and steel fabrication. Johnson and Tatum (1993) also emphasise the high propensity for marine construction to adopt new technical knowledge. Tang and Bittner (2014) highlight the need for an approach that can determine the success factors of projects conducted in an uncertain marine environment.

Knowledge management is essential in ensuring improving project performance. Given that knowledge formation is a critical component of knowledge management, considering how to apply knowledge in every stage of a project, particularly in earlier stages is important (Ahmadi and Sutrisna, 2018). It is widely acknowledged in the literature that knowledge is a success factor of a project that can help to achieve benchmarks in marine construction projects. In addition, knowledge management is emphasised as an effective system for advancing project efficiency. However, there is limited evidence about the effect of employing knowledge in different phases of marine construction projects, particularly in the front-end phase. Further, the correlation between knowledge as a success factor of projects and its effect on project factors such as efficiency, productivity, performance and schedule when employed in the early stages of a project's life cycle is not well reported in the literature. Consequently, it is imperative to investigate and develop mechanisms that aim to improve project efficiency other than generic project-management approaches that are well researched in the literature. Accordingly, this paper conducts the present literature review to highlight the significance of using knowledge in the early stages in a project's success, and to explore applicable protocols that can help project success by offering new opportunities for improving efficiency in marine construction projects.

The findings from Karami and Olatunji (2018c) highlight the benefits of employing VE protocols in marine construction projects to integrate science and empirical knowledge into design alternatives. Although VE is often mistaken as a cost-trimming tool (Wao, 2015), future research must consider other useful aspects of this systematic approach to project management.

Value engineering justification

According to Karami and Olatunji (2018c), success in a project is often identified by evaluating the leading variables of VE (i.e., schedule, budget, quality and safety standards). Knowledge plays a significant role in the efficiency and effectiveness of these variables in contributing to the successful completion of projects. However, there are impediments associated with administering knowledge throughout different stages of construction projects. Ahmadi and Sutrisna (2018) state that the challenges that affect a project's success are difficulty in information sharing, ambiguity in activities, and challenges in using the lessons learnt. It is essential for a practical method to be employed in the context of marine construction that is capable of amending these issues and identifying management protocols to deal with critical conditions (Tang and Bittner, 2014).

Researchers acknowledge that VE is an effective approach to addressing problems resulting from the diverse impediments of uncertain marine environment. Empirical evidence and research argue that some of these impediments can be controlled, particularly in the early stages of a marine construction project before construction begins (Kenny and Vanissorn, 2012, Elias, 1998). Research also finds that the greatest benefit will be obtained from VE when it is used in the early stages of a marine construction project, particularly in the front-end phase. However, Ilayaraja and Eqyaabal (2015) believe in the effectiveness of employing VE during all stages of the project's life cycle. Likewise, Shaw (2016) argues that the effectiveness of using VE in improving project efficiency throughout the life cycle of a project is in line with the effectiveness of other success factors such as knowledge.

Based on a large number of case studies conducted in the marine environment, Tang and Bittner (2014) list the following seven steps of the VE process: gathering information, analysing function, generating solutions, evaluating solutions, selecting and developing solutions, eliciting the optimum plan, and monitoring the execution plan. All the challenges associated with knowledge management can find correspondences in these seven VE factors. Using knowledge as a catalyst in VE workshops for marine construction projects facilitates the process of maximising project value, mitigates possible ambiguity in activities, and integrates all relevant information and lessons learnt, thus enabling the project to perform efficiently throughout its life cycle. Many studies find that the VE approach allows the integration of information relating to different options for a project's components, and their expected lifespan performance, as well as to their designed purposes (Shen and Liu, 2003, Goh et al., 2012). Considering the large scale and high degree of complexity, uncertainty and economic value related to marine construction projects, VE is considered the most adequate approach to integrating specialised knowledge in the early stages of such projects.

IMPLICATIONS

This study has discussed the significance of knowledge in improving efficiency in a marine construction project's front-end phase, particularly considering the importance of VE as a problem-solving tool in this process. VE refers to using a team of experts from different disciplines to cooperate and initiate optimum solutions to assist a project's team and ensure the satisfaction of stakeholders. Hunter and Kelly (2004) argue that VE helps to envision and mitigate issues that may arise throughout a project's life cycle by considering predictive and preventive action plans from the early stages of a project. Unless knowledge is integrated, this is not possible. That is, knowledge itself can be considered an integrated part of the VE mechanism.

In addition, efficiency in construction projects is highly related to recognising success factors related to the project's scope and environment. Karami and Olatunji (2018c) categorised success factors in marine infrastructures into the following ten themes: 1) financial stability; 2) appropriate planning; 3) technical strength; 4) safety and risk-related protocols; 5) implementation procedures; 6) design appropriateness; 7) lessons learnt; 8) efficient management strategies; 9) ethical commitment of the team involved; 10) adequate supportive machinery department. Having knowledge integrated into these factors greatly improves efficiency, and the effectiveness greatly depends on employing these success factors at the early stages of a project's life cycle.

PROPOSED FRAMEWORK FOR FUTURE RESEARCH

Based on the literature and findings from this study, the relationship between VE and knowledge is summarised in the proposed framework. This framework was created by integrating the information in the two graphs that present the effectiveness of VE (Figure 1) and knowledge maturity (Figure 2) in different project stages. Figure 1 demonstrates the importance of employing VE in the early stages of a project. The final outcome is presented in Table 1.

Marine construction projects will benefit from this proposed framework because it can help in restrategising action plans, revising design assumptions, and substituting implementation plans, which all help to ensure the ideal completion of a project.

Knowledge gained and lessons learnt can be considered inputs for future projects
This input can be discussed in VE workshops, leading to the formation of a knowledge platform
Elicited knowledge pool facilitates codifying and documenting implicit knowledge in the knowledge-management process
This helps construction industry, stakeholders and project management to better understand the beneficial effect of knowledge and how to use dedicated mechanisms based on the scale and context of the project
Implementing this approach will form a culture in organisations and builds a foundation for managing knowledge at different levels

Table 1: Knowledge and VE integration effectiveness

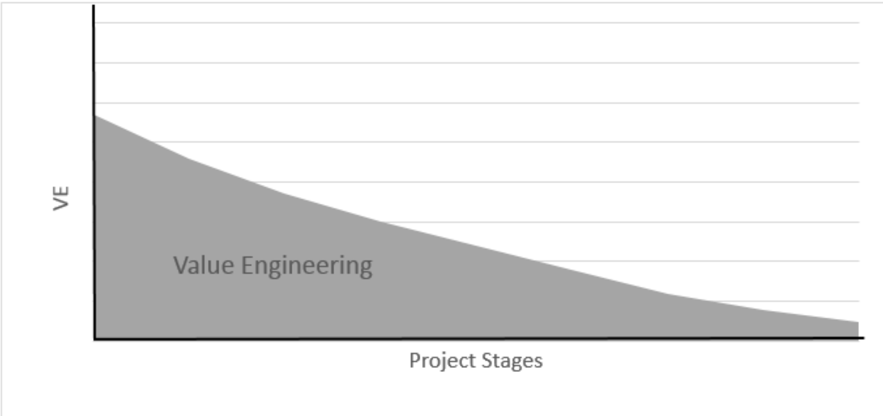

Figure 1: Effectiveness of VE in different project

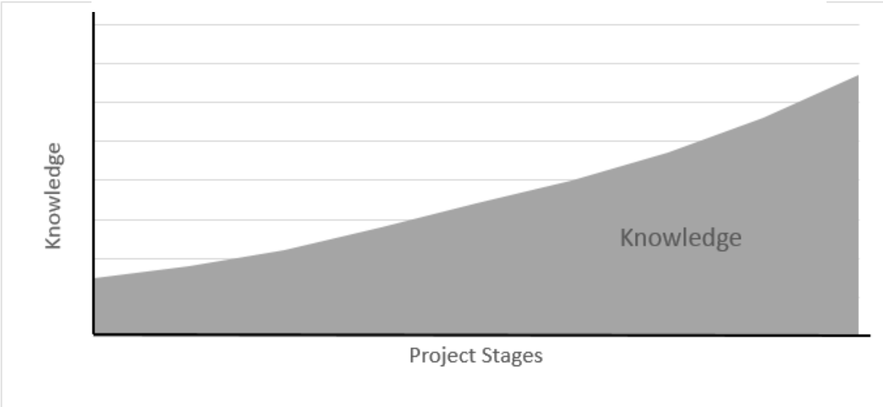

Figure 2: Knowledge maturity in different project

Marine construction projects are challenging. While such projects play a significant role in the economic development of many countries, there is little research evidence for robust management strategies to advance the efficiency of these projects. The present study argues that employing knowledge in the early stages of a project can improve project efficiency in the uncertain and often-volatile marine environment. This study aimed to highlight the role of knowledge as a catalyst in facilitating the performance of practical approaches, VE in particular, to project management. Thus, knowledge was examined as a critical success factor in project management, and the association between knowledge and VE, and the effect of this association on efficiency and effectiveness in the front-end phase of marine construction projects was discussed.

The proposed framework was created based on the literature review and the relationship between knowledge and VE in the early stages of a construction project. The framework is designed to support further research in this area. It is important that further research is conducted to explore how knowledge and VE can be employed to ensure success in complicated construction projects such as those undertaken in the marine environment. Further research employing this framework will more readily allow the identification of new strategies based on project scale and the unique characteristics of different projects. The following stage of this present research study plans to examine other stages of a project's life cycle and determine the relationship between knowledge and VE in these stages.

REFERENCES

AHMADI, L. & SUTRISNA, M. 2018. categorizing the key factors of knowledge-based projects for improving their performance. *Proceeding of International Conference on Durability of Building and Infrastructures*, 250-253.

BOU, E. & SAUQUET, A. 2004. Reflecting on quality practices through knowledge management theory: uncovering grey zones and new possibilities of process manuals, flowcharts and procedures. *Knowledge Management Research & Practice,* 2**,** 35.

BUONO, A. 1996. The knowledge creating company: How Japanese companies create the dynamics of innovation - Nonaka,I, Takeuchi,H. *Pers. Psychol.*

CARRILLO, P. & CHINOWSKY, P. 2006. Exploiting Knowledge Management: The Engineering and Construction Perspective. *Journal of Management in Engineering,* 22**,** 2-10.

CLOUGH, R. H. 2000. *Construction project management / by Richard H. Clough, Glenn A. Sears, S. Keoki Sears,* New York, New York : Wiley.

DESOUZA, K. C. & EVARISTO, J. R. 2006. Project management offices: A case of knowledge-based archetypes. *International Journal of Information Management,* 26**,** 414-423.

DISTERER, G. 2002. Management of project knowledge and experiences. *Journal of Knowledge Management,* 6**,** 512-520.

ELENA, B. & ALFONSO, S. 2004. Reflecting on quality practices through knowledge management theory: uncovering grey zones and new possibilities of process manuals, flowcharts and procedures. *Knowledge Management Research & Practice,* 2**,** 35.

ELIAS, S. E. G. 1998. Value engineering, A powerful productivity tool. 381-393.

GOH, Y. M., LOVE, P. E. D., BROWN, H. & SPICKETT, J. 2012. Organizational accidents: a systemic model of production versus protection. *Journal of Management Studies,* 49**,** doi: 10.1111/j.1467-6486.2010.00959.x.

HANISCH, B., LINDNER, F., MUELLER, A. & WALD, A. 2009. Knowledge management in project environments. *Journal of Knowledge Management,* 13**,** 148-160.

HUNTER, K. & KELLY, J. 2004. The case for value management in the UK public service sector. *ARCOM (Association of Researchers in Construction Management) proceedings*, 1031-1041.

ILAYARAJA, K. & EQYAABAL, Z. M. D. 2015. Value Engineering in Construction. *Indian Journal of Science and Technology,* 8.

JOHNSON, K. D. & TATUM, C. B. 1993. Technology in Marine Construction Firms. *Journal of Construction Engineering and Management,* 119**,** 148-162.

KAMARA, J. M., AUGENBROE, G., ANUMBA, C. J. & CARRILLO, P. M. 2002. Knowledge management in the architecture, engineering and construction industry. *Construction Innovation,* 2**,** 53-67.

KANG, J. 2007. Testing impact of knowledge characteristics and relationship ties on project performance. *Journal of Knowledge Management,* 11**,** 126-144.

KARAMI, H. & OLATUNJI, O. 2018a. Contractor selection model for marine projects. *Proceeding of International Conference on Durability of Building and Infrastructures.* Singapore.

KARAMI, H. & OLATUNJI, O. A. 2018b. Delay causations in marine infrastructures, a review. *Proceeding of International Conference on Durability of Building and Infrastructures*, 167-170.

KARAMI, H. & OLATUNJI, O. A. 2018c. Key success factors in marine infrastructures, a review. *Proceeding of 42nd Australasian Universities Building Education Association*

(AUBEA) Conference on Educating Building Professionals for the Future in the Globalised World, 121-128.
KENNY, W. & VANISSORN, V. 2012. A study of the factors affecting construction time in Western Australia. *Scientific Research and Essays,* 7, 3390-3398.
KOSKINEN, K. 2004. KNOWLEDGE MANAGEMENT TO IMPROVE PROJECT COMMUNICATION AND IMPLEMENTATION. *Project Management Journal,* 35, 13-19.
LAMPEL, J., SCARBROUGH, H. & MACMILLAN, S. 2008. Managing through Projects in Knowledge-based Environments: Special Issue Introduction by the Guest Editors. *Long Range Planning,* 41, 7-16.
LIN, Y.-C., WANG, L.-C. & TSERNG, H. P. 2006. Enhancing knowledge exchange through web map-based knowledge management system in construction: Lessons learned in Taiwan. *Automation in Construction,* 15, 693-705.
SAMIE, N. N. 2016. Disciplines Involved in Offshore Platform Design. *Practical Engineering Management of Offshore Oil and Gas Platforms.*
SERPELLA, A. F., FERRADA, X., HOWARD, R. & RUBIO, L. 2014. Risk Management in Construction Projects: A Knowledge-based Approach. *Procedia - Social and Behavioral Sciences,* 119, 653-662.
SHAW, J. 2016. Value for Money (VfM) in construction is the optimum balance between managing costs without compromising on quality.
SHEKARCHI, M., MORADI-MARANI, F. & PARGAR, F. 2011. Corrosion damage of a reinforced concrete jetty structure in the Persian Gulf: a case study. *Structure and Infrastructure Engineering,* 7, 701-713.
SHEN, Q. & LIU, G. 2003. Critical success factors for value management studies in construction. *Journal of Construction Engineering and Management,* 129, 485-491.
TAM, V. W. Y. 2012. Risk Management for Contractors in Marine Projects. *Organization, technology and management in construction, an international journal* 4, 403-410.
TAN, H. C., ANUMBA, C. J., CARRILLO, P. M., D., B., J., K. & C., U. 2010. Capture and reuse of project knowledge in construction. Portland: Ringgold Inc.
TANG, P. & BITTNER, R. B. 2014. Use of Value Engineering to Develop Creative Design Solutions for Marine Construction Projects. *Practice Periodical on Structural Design and Construction,* 19, 129-136.
TODOROVIĆ, M. L., PETROVIĆ, D. Č., MIHIĆ, M. M., OBRADOVIĆ, V. L. & BUSHUYEV, S. D. 2015. Project success analysis framework: A knowledge-based approach in project management. *International Journal of Project Management,* 33, 772-783.
WAO, J. 2015. A Review of the Value Engineering Methodology: Limitations and Solutions for Sustainable Construction.